General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

NASA CR - 135412

NASA

PREDICTION OF HYDRODYNAMICS AND CHEMISTRY OF CONFINED TURBULENT METHANE - AIR FLAMES IN A TWO CONCENTRIC TUBE COMBUSTOR

by N. C. Markatos, D. B. Spalding and S. K. Srivatsa

CONCENTRATION, HEAT AND MOMENTUM LIMITED

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research center
Contract NASW - 3077

Cham of North America Incorporated
3400 Blue Spring Rd, Huntsville, Ala. 35810

PREDICTION OF THE HYDRODYNAMICS AND CHEMISTRY OF METHANE-AIR FLAMES IN A TWO CONCENTRIC TUBE COMBUSTOR

NASA CR-135412

by N.C. Markatos, D.B. Spalding and S.K. Srivatsa

CONCENTRATION, HEAT AND MOMENTUM LIMITED

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NASA Lewis Research Center

Contract NASW-3077

JULY 1978 CHAM 957/2

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
PREDICTION OF THE HYDRODYNAMICS AND CHEMISTRY OF METHANE-AIR FLAMES IN A TWO CONCENTRIC TUBE COMBUSTOR	JUNE 1978
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
N.C. Markatos, D.B. Spalding, S.K. Srivatsa	CHAM 957/2
	10. Work Unit No.

9. Performing Organization Name and Address	11. Contract or Grant No.
Concentration, Heat and Momentum Ltd., Bakery House, 40 High Street, Wimbledon, London, SW19 5AU, England.	NASW-3077
	13. Type of Report and Period Covered Contractor Report 5/77-4/78

12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
National Aeronautics and Space Administration, NASA-Lewis Research Center, Cleveland, Ohio.	

15. Supplementary Notes

Project Manager, A.J. Juhasz,
Power Generation and Storage Division, NASA-Lewis Research Center, Cleveland, Ohio.

16. Abstract

A formulation of the governing partial differential equations for fluid flow and reacting chemical species in a two-concentric-tube combustor is presented. A numerical procedure for the solution of the governing differential equations is described and models for chemical-equilibrium and chemical-kinetics calculations are presented. The chemical-equilibrium model is used to characterise the hydrocarbon reactions. The chemical-kinetics model is used to predict the concentrations of the oxides of nitrogen. The combustor considered consists of two coaxial ducts. Concentric streams of gaseous fuel and air enter the inlet duct at one end; the flow then reverses and flows out through the outer duct. Two sample cases with specified inlet and boundary conditions are considered and the results are discussed.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Two-concentric-tube combustor Combustion nitric oxides pollutants	Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161

TABLE OF CONTENTS

1. INTRODUCTION

1.1 The problem considered

The problem considered in the present report involves the development of a general-purpose computer program for the realistic prediction of the hydrodynamics and chemical reaction in a two-concentric-tube combustor; special attention being given to pollutant (NO_x) formation.

The combustor geometry considered in this study is shown in Figure 1. As indicated in the Figure, concentric streams of fuel (methane) and air enter the inner duct of diameter $D_{1,i}$ and length L_1. On entering the duct, the fuel and air mix together and at the end of the inner duct, the flow expands radially outward and flow reversal occurs into the passage of inner diameter $D_{2,i}$. Combustion occurs in the flow reversal region. Oxides of nitrogen and other combustion products are formed as a result of the chemical reaction.

The flow is two-dimensional, axisymmetric, steady and turbulent.

1.2 Connexions with previous work

The method of solution employed is based on Ref 1, which describes a general computer program (CHAMPION 2/E/FIX) for two-dimensional elliptic flows. While the solution procedure employed in the present work is basically the same as that of Ref 1, the computer program itself has been extensively modified in order to improve its structure, efficiency and comprehensibility. In addition, the present work has also involved the inclusion of heat transfer effects and of the appropriate chemical-equilibrium and kinetics-calculation schemes.

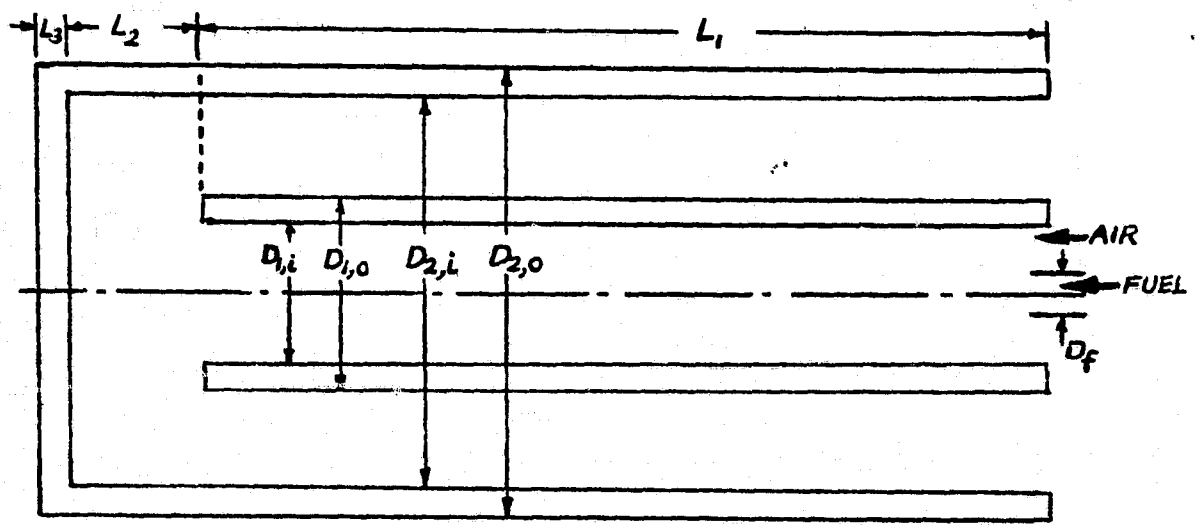


Figure 1: Geometry of a two-concentric- tube combustor (not to scale).

1.3 Purpose of the report

The purpose of this report is to present the analysis of the hydrodynamics and the chemical reaction in the two-concentric-tube combustor (Fig. 1). The analysis involves the mathematical formulation of the flow in terms of partial differential and some auxiliary algebraic equations. Subsequently these equations are cast in their finite-difference form for obtaining numerical solutions. The solution procedure is incorporated in a computer program to produce profiles of velocity, temperature, and species concentrations throughout the combustor.

This report provides all the necessary information concerning the mathematical modelling of the flows under consideration, it describes the numerical analysis involved in the solution of the relevant equations and it defines the user-orientated parts of the program.

It is to serve as both a comprehensive reference to the mathematics and numerical procedure used in the program and as an operational manual for the computer program.

1.4 Layout of the report

The remainder of this report is divided into ten chapters. Chapter 2 is concerned with the mathematical formulation and physical models employed in the solution procedure. Chapter 3 details the numerical solution procedure, and Chapter 4 describes further features of the calculation. Thermodynamic and element data are discussed in Chapter 5, and kinetics data in Chapter 6. Results and discussions are provided in Chapter 7, and Chapter 8 provides some concluding remarks. Relevant literature references and nomenclature are given in Chapters 9 and 10 respectively, which close this report. Appendices A and B contain the description

and the listing of the computer program. Appendix C contains a glossary of Fortran variables used in the computer program; and Appendix D contains a partial listing of the output from the program.

2. PHYSICAL AND MATHEMATICAL ANALYSIS

2.1 Introduction

This Chapter describes the mathematical and physical basis of the problem considered. The physical modelling of properties and processes is discussed in Section 2.2. Section 2.3 outlines the conservation equations for mass, momentum, stagnation enthalpy, and chemical species. Boundary conditions are considered in Section 2.4. Auxiliary equations for mixture properties and flux calculations are dealt with in Section 2.5. Section 2.6 describes the chemical-equilibrium model, and Section 2.7 the chemical-kinetics model.

2.2 Physical Models

The conservation equations outlined in the next section are based on a physical model which involves certain assumptions regarding properties and processes; these are now described.

2.2.1 Processes

(i) Axial and radial derivatives for conduction, diffusion, and momentum transport are included in the conservation equations.

(ii) The chemistry incorporated into the computer code is as follows:

(1) A single-step reaction for hydrocarbon oxidation according to:

1 kg of fuel + s kg of oxygen → (1+s) kg products

(1)

where s is a fixed stoichiometric ratio , and the rate of the reaction is governed by the Arrhenius relation:

$$\text{Rate} = C_1 \, T^{C_2} m_{fu}^{C_3} m_{ox}^{C_4} \exp(-C_5/T) \qquad (2)$$

where C_1, C_2, C_3, C_4, and C_5, are constants, T is the absolute temperature, and m_{fu} and m_{ox} are the concentrations of fuel and oxygen respectively.

(2) The products of the above idealized reaction are assumed to consist of the species: CO, CO_2, H_2O, O, H, H_2, and OH, in such proportions as are appropriate to equilibrium stoichiometric adiabatic combustion at the prevailing pressure and enthalpy. These proportions are represented as algebraic functions of pressure and enthalpy; the constants in these functions being determined from interpolations in equilibrium computations made external and prior to the main computer code.

(3) Oxides of nitrogen are calculated by reference to the kinetically-controlled reactions involving the species N_2, O_2, O, H, and OH. The scheme consists of nine reactions including the Zeldovich mechanism as shown in Section 2.7 below.

2.2.2 Properties

Transport-property assumptions are such as to allow a composite property ξ ($\equiv m_{fu} - m_{ox}/s$) to characterise the composition of the gas-mixture with respect to the products of combustion resulting from the main hydrocarbon oxidation reaction. The quantity ξ obeys a source-free conservation equation, and its transport coefficient is a function of position alone. This means that ξ is influenced by convection and diffusion alone; and underlying its definition

is the assumption that the transport properties of oxidant and fuel are everywhere equal.

2.3 Governing Differential Equations

The dependent variables are the axial velocity u, radial velocity v, pressure p, mixture fraction f, mass fraction of unburnt fuel m_{fu}, stagnation enthalpy $\tilde{h}$ and the mass fractions of the species involved in the NO_x- reactions (i.e. NO, NO_2, N, and N_2O). As mentioned earlier in Section 2.2.1, the concentrations of the species CO, CO_2, H_2O, O, H, H_2, and OH are determined by a chemical-equilibrium analysis, subsequent to the solution of the governing differential equations for f and m_{fu}.

The differential equations which govern the fluid flow for steady, two-dimensional axisymmetric flow are written* in cylindrical polar (x-r) coordinates as:

x-direction momentum equation:

$$\frac{\partial}{\partial x}(\rho u^2) + \frac{1}{r}\frac{\partial}{\partial r}(\rho r v u) - \frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right) - \frac{1}{r}\frac{\partial}{\partial r}\left(r\mu\frac{\partial u}{\partial r}\right)$$

$$= -\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left(r\mu\frac{\partial v}{\partial x}\right) \qquad (3)^{**}$$

---

* Symbols are explained in the nomenclature (Chapter 10).

** In the equations presented here and later in the report, μ and Γ are the effective transport coefficients; the subscript 'eff' is however largely omitted for the sake of convenience.

r-direction momentum equation:

$$\frac{\partial}{\partial x}(\rho uv) + \frac{1}{r}\frac{\partial}{\partial r}(\rho r v^2) - \frac{\partial}{\partial x}\left(\mu \frac{\partial v}{\partial x}\right) - \frac{1}{r}\frac{\partial}{\partial r}\left(r\mu \frac{\partial v}{\partial r}\right)$$

$$= -\frac{\partial p}{\partial r} + \frac{\partial}{\partial x}\left(\mu \frac{\partial u}{\partial r}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left(r\mu \frac{\partial v}{\partial r}\right) - \frac{2\mu v}{r^2} \qquad (4)$$

Continuity equation:

$$\frac{\partial}{\partial x}(\rho u) + \frac{1}{r}\frac{\partial}{\partial r}(\rho r v) = 0 \qquad (5)$$

Conservation equation for chemical species j

$$\frac{\partial}{\partial x}(\rho u m_j) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho v m_j) - \frac{\partial}{\partial x}\left(\Gamma_j \frac{\partial m_j}{\partial x}\right) - \frac{1}{r}\frac{\partial}{\partial r}\left(\Gamma_j r \frac{\partial m_j}{\partial r}\right) = R_j \qquad (6)$$

where m_j is the mass fraction of chemical species j and R_j is the mass rate of creation of species j by chemical reaction.

Conservation equation for stagnation enthalpy $\tilde{h}$:

$$\frac{\partial}{\partial x}(\rho u \tilde{h}) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho v \tilde{h}) - \frac{\partial}{\partial x}\left(\Gamma_{\tilde{h}} \frac{\partial \tilde{h}}{\partial x}\right) - \frac{1}{r}\frac{\partial}{\partial r}\left(\Gamma_{\tilde{h}}\, r \frac{\partial \tilde{h}}{\partial r}\right) = S_{\tilde{h}} \qquad (7)$$

where $S_{\tilde{h}}$ represents the sum of all the source terms for $\tilde{h}$ and includes sources of radiation and heat fluxes at the walls of the duct. To arrive at equation (7), the assumption has been made that the exchange coefficients for the transport of the mixture and that for heat conduction are all equal at a point, although they may vary from point to point.

Conservation equation for mixture fraction f:

$$\frac{\partial}{\partial x}(\rho u f) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho v f) - \frac{\partial}{\partial x}\left(\Gamma_f \frac{\partial f}{\partial x}\right) - \frac{1}{r}\frac{\partial}{\partial r}\left(\Gamma_f r \frac{\partial f}{\partial r}\right) = 0 \qquad (8)$$

where the mixture fraction f is defined as

$$f \equiv (\xi - \xi_{ox}) \;/\; (\xi_{fu} - \xi_{ox}) \qquad (9)^*$$

General form of governing differential equations:

Equations (3) to (8) may be written in a general form as:

$$\frac{\partial}{\partial x}(\beta u \phi) + \frac{1}{r}\frac{\partial}{\partial r}(r\beta v\phi) - \frac{\partial}{\partial x}(\Gamma_\phi \frac{\partial \phi}{\partial x}) - \frac{1}{r}\frac{\partial}{\partial r}(\Gamma_\phi r \frac{\partial \phi}{\partial r}) = S_\phi \qquad (10)$$

In the above equation ϕ identifies the dependent variable, β is identically equal to either the mixture density ρ or zero; Γ_ϕ is the appropriate exchange coefficient for the variable ϕ; and S_ϕ is the source term which includes both the sources of ϕ(positive or negative) and any other terms which cannot find a place on the left-hand side of the equation. Table 1 summarizes the equations in the form that are solved in the present work. Some notes about these equations now follow:

- The terms involving the velocity divergence (div $\vec{V}$) in the source terms of the x- and r-momentum equations have been ignored. For uniform-density (i.e. inert) flows div $\vec{V}$ is identically zero and there is no error involved. For the chemically reacting flows to be handled in the present work, div $\vec{V}$ is expected to be small compared to other terms in the momentum equations, and its omission will introduce small errors only.

---

* Note: $\xi_{ox} = (-m_{ox})_{inlet}/s$ and $\xi_{fu} = (m_{fu})_{inlet}$,
where m_{ox} is the oxygen mass fraction in the incoming oxidant stream and m_{fu} is the fuel mass fraction in the incoming fuel stream.

Table 1. Summary of Equations

Equation	ϕ	β	Γ_ϕ	S_ϕ
Continuity, Eq. (5)	1	ρ	0	0
x-momentum, Eq. (3)	u	ρ	μ	$-\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}(\mu\frac{\partial u}{\partial x}) + \frac{1}{r}\frac{\partial}{\partial r}(r\mu\frac{\partial v}{\partial x})$
r-momentum, Eq. (4)	v	ρ	μ	$-\frac{\partial p}{\partial r} + \frac{\partial}{\partial x}(\mu\frac{\partial u}{\partial r}) + \frac{1}{r}\frac{\partial}{\partial r}(r\mu\frac{\partial v}{\partial r}) - \frac{2\mu v}{r^2}$
Fuel mass fraction, Eq.(6)	m_{fu}	ρ	μ/Sc_{fu}	Rate from equation(2).
Mixture fraction, Eq.(8)	f	ρ	μ/Sc_f	0.
NO_x-species, Eq. (6)	m_j	ρ	μ/Sc_j	Rate from equation (43).
Stagnation enthalpy, Eq.(7)	$\tilde{h}$	ρ	$\mu/Pr_{\tilde{h}}$	0 (except for boundary fluxes; see section 4.3).

- Since the flow is turbulent, time-average values of flow variables and effective values of the exchange coefficients must be used.

2.4 Boundary conditions

Boundary conditions are required for the dependent variables at all the boundaries of the flow domain. These are now discussed below.

2.4.1 Inlet boundary

(a) u-velocity : The inlet u-velocities of the fuel and air streams are obtained from their specified mass flow rates via the continuity relations:

$$u_{fo} = \frac{m_{fo}}{\rho_{fuel} \left(\frac{\pi}{4} D_f^2\right)} \tag{11}$$

$$u_{ao} = \frac{m_{ao}}{\rho_{air} \frac{\pi}{4} \left(D_{1,i}^2 - D_f^2\right)} \tag{12}$$

(b) v-velocity : The inlet v-velocity is assumed to be zero.

(c) Pressure : The inlet pressure is assumed uniform at the specified value of P_o.

(d) Chemical species and mixture fraction : In the inlet fuel stream, the fuel mass fraction (and mixture fraction) is set to unity; all other species mass fractions are set to zero. In the inlet air stream, the oxygen mass fraction is set to 0.232, and the nitrogen mass fraction to 0.768; all other species mass fractions (and mixture fraction) are set to zero.

(e) Stagnation enthalpy : The inlet stagnation enthalpy in the fuel and air streams is calculated from the specified inlet temperature and mixture composition by the equations given in Section 5.2.

2.4.2 Outlet boundary

(a) u-velocity : The outlet boundary condition for u-velocity is assumed to be that of zero axial gradient, i.e.

$$\frac{\partial u}{\partial x} = 0 \text{ at the exit} \qquad (13)$$

(b) v-velocity : The outlet v-velocity is assumed to be zero, this follows from the outlet boundary condition on u-velocity.

(c) Pressure : For pressure, an outlet boundary condition of uniform pressure is employed.

(d) Chemical species, mixture fraction and stagnation enthalpy :

The outlet boundary condition for chemical species, mixture fraction and stagnation enthalpy is again assumed to be that of zero axial gradient, i.e.

$$\left.\begin{aligned} \frac{\partial m_j}{\partial x} &= 0 \qquad (14)\\ \frac{\partial f}{\partial x} &= 0 \qquad (15)\\ \frac{\partial \tilde{h}}{\partial x} &= 0 \qquad (16) \end{aligned}\right\} \text{ at the exit}$$

2.4.3 Axis of symmetry

At this boundary, a condition of zero radial gradient is assumed

for all dependent variables except the v-velocity which is set to zero.

2.4.4 The wall boundaries

The treatment of wall boundaries is discussed in Chapter 4 after the finite-difference equations have been derived in Chapter 3. The reason is that the treatment of the wall boundaries requires reference to the finite-difference equations.

2.5 Auxiliary Relations

In this section some auxiliary relations, and the assumptions associated with their use are introduced. These relations are used for the calculation of fluxes and certain properties.

2.5.1 Flux laws

Implicit in the differential equations given in Section 2.3 are the flux laws for the transport of momentum, mass and heat. These laws will now be summarised, for laminar and turbulent flows.

(a) Laminar transport properties:

(i) Viscosity: Newton's law of viscosity for momentum transfer, relating the shear stress τ to the local velocity gradient, through the laminar viscosity, μ, can be expressed for simple flows as:

$$\tau = \mu(\partial u/\partial y) \qquad (17)$$

(ii) Diffusion coefficient: Fick's law of diffusion for mass transfer, relating the diffusion mass flux J_j, to the concentration gradient, through the exchange

coefficient, Γ_j, has the form:

$$J_j = -\Gamma_j \, (\partial m_j/\partial y), \text{ for the species } j \qquad (18)$$

The diffusion coefficient Γ_j is obtained from the definition of Schmidt number. Thus,

$$\Gamma_j = \mu/Sc_j \qquad (19)$$

It has been assumed in the solution procedure that the Schmidt numbers for fuel and oxygen (and all the other species) are equal to each other, and also uniform throughout the flow field.

(iii) Thermal conductivity: Fourier's law of heat conduction, relating the heat flux Q to the temperature gradient, through the exchange coefficient, $\Gamma_h^{\sim}$, can be written as:

$$Q = -\Gamma_h^{\sim} \, c(\partial T/\partial y) \qquad (20)$$

where c stands for the constant-pressure specific heat of the local gas mixture.

In the present analysis, $\Gamma_h^{\sim}$ is obtained from a knowledge of the mixture viscosity μ and the laminar Prandtl number:

$$\Gamma_h^{\sim} = \mu/Pr_h^{\sim} \qquad (21)$$

In general, the laminar Prandtl number (or the exchange coefficient $\Gamma_h^{\sim}$ itself) can, if desired, be specified as any arbitrary function of temperature and composition; this will make $\Gamma_h^{\sim}$ depend upon temperature and composition in a way different from μ.

(b) Turbulent transport properties:

For a realistic modelling of the flow, the effect of turbulence has to be included whenever appropriate. The scope of the present contract does not permit the treatment of turbulence by means of a sophisticated model. Instead a simply zero-equation model of turbulence is employed.

(i) Viscosity: The turbulent shear stresses are linked to the local velocity gradient through a laminar-like stress-strain law:

$$\tau = \mu_{eff} \left| \frac{\partial u}{\partial y} \right| \quad . \tag{22}$$

For the present work, the effective viscosity is assumed to be uniform throughout the flow field. This uniform value is obtained from an empirical relation which gives a value of μ_{eff} of the same order as expected in flows of the type under consideration:

$$\mu_{eff} = \frac{0.12(m_{fo}+m_{ao})}{D_{1,i}} \tag{23}$$

where m_{fo} and m_{ao} are the inlet fuel and air mass flow rates and $D_{1,i}$ is the inner diameter of the inner tube.

(ii) Diffusion coefficient and thermal conductivity: The effective diffusion coefficients for the transfer of mass and energy are obtained from the definitions of Schmidt and Prandtl numbers respectively.

Thus, for mass transfer, $\Gamma_{eff} = \mu_{eff}/Sc_{eff}$ (24)

and for heat transfer, $\Gamma_{eff} = \mu_{eff}/Pr_{eff}$ (25)

2.5.2 Temperature of the mixture

The temperature of the mixture, T, at a given point in the flow field, is obtained from known local values of the stagnation enthalpy $\tilde{h}$ and the composition of the mixture as follows:

$$\tilde{h} = \sum_{j=1}^{NS} m_j \, h_j \qquad (26)$$

where the species enthalpy h_j is obtained by the method described in Section 5.2 on thermodynamic data. The fluid temperature is then obtained as described in Section 5.2.

2.5.3 The ideal-gas equation of state

For a given temperature, the pressure and the density are assumed to be related through the ideal gas-equation:

$$p = \frac{\rho R T}{\overline{W}} \qquad (27)$$

where $\overline{W}$, the mean molecular weight of the gas mixture, is given by

$$\overline{W} = 1/\sum_{j=1}^{NS} (m_j/W_j) \qquad (28)$$

2.6 The Chemical-Equilibrium Model

2.6.1 Introduction

The chemistry involved in the hydrocarbon-oxidation process (Sec. 2.2.1) will now be described. The oxidation reaction is assumed to be a single-step one and results in some product species. These species are in chemical equilibrium at the prevailing pressure and enthalpy. Their concentrations are obtained from a model which is based on the minimization of Gibbs free energy. The method

has been described by Gordon and McBride (Ref. 2).

2.6.2 Species considered

The equilibrium products of combustion are considered to consist of the following species: CO, CO_2, H_2O, O, H, H_2, and OH, together with unburnt O_2 and CH_4, and N_2. The last of these is assumed to be inert in the equilibrium reactions.*

2.6.3 Equations of chemical-equilibrium

The chemical-equilibrium equations to obtain the concentrations of the equilibrium-product-species have been discussed in detail in Ref. 2. Here the basis of their derivation will be only briefly described. The condition of chemical equilibrium is the minimization of Gibbs free energy subject to the following constraints: (a) mass balance for the elements present in the system; (b) specified enthalpy and (c) specified pressure. Since the resulting equations are not all linear, they have to be solved by an iterative procedure. The numerical method of solution of these equations is described in Section 3.5. Here the basic steps for obtaining the chemical-equilibrium composition are considered.

2.6.4 Procedure for obtaining chemical-equilibrium compositions

The basic steps for obtaining the concentrations of the species CO, CO_2, H, H_2, H_2O, O, and OH are:

- The stagnation enthalpy, $\tilde{h}$, the mixture fraction, f, and the mass fraction of unburnt fuel, m_{fu}, are obtained

---

* N_2 is of course not inert in the NO_x-formation reactions; but these will be treated separately (Sec. 2.7).

from the solution of the respective partial differential equations (7, 8, and 6).

- The mass fraction of unburnt oxygen, m_{ox}, is obtained from:

$$m_{ox} = (m_{fu} - \frac{f - f_{st}}{1 - f_{st}})s \qquad (29)$$

where f_{st} is the stoichiometric value of f. Should the value of m_{ox} be less than zero, during the iterative solution, it is set equal to zero (or a small quantity for programming convenience).

- The mass fraction of the equilibrium-product-species m_{pr}, is given by:

$$m_{pr} = (f - m_{fu})\ (1 + s) \qquad (30)$$

- The mass fraction of nitrogen, m_{N_2}, is given by:

$$m_{N_2} = 1 - m_{fu} - m_{ox} - m_{pr} - \sum_j m_j \qquad (31)$$

where the summation is carried out over the species N, NO, NO_2, and N_2O which are determined through rate-controlled reactions.

- The enthalpy of the equilibrium-product-species, h_{pr}, is then:

$$h_{pr} = \{\tilde{h} - \sum_j h_j m_j\} \ / m_{pr} \qquad (32)$$

where the summation is over all species other than the equilibrium-product-species (CO, CO_2, H, H_2, H_2O, O, and OH).

- For a given value of enthalpy (h_{pr}) and pressure the equilibrium-product-species concentrations for stoichiometric adiabatic combustion are obtained by means of interpolations using polynomial fits* in accordance with the method described in Section 3.5.4. These concentrations are then multiplied by a factor so that they add to m_{pr}, i.e.

$$m_{CO} + m_{CO_2} + m_H + m_{H_2O} + m_O + m_{OH} = m_{pr} \qquad (33)$$

- At this stage, the mass fractions of all species except the pollutant-species N, NO, NO_2, and N_2O have been determined. Since the latter are present in small amounts the values of these from the previous iterative sweep are used, and the temperature of the mixture obtained as per Section 3.7.

- The next step is the determination of the mass fractions of the pollutant species N, NO, NO_2, and N_2O. This is considered in the following section.

2.7 Treatment of Chemical-Kinetics

2.7.1 Introduction

Oxides of nitrogen are formed during the course of combustion

---

* The determination of the polynomial coefficients is done external and prior to the main computer code.

reactions involving air as oxidant. These species are considered separately from the equilibrium species since their formation is governed by much slower kinetically-controlled reactions. The determination of the concentrations of these pollutant species involves a treatment of chemical-kinetics. This is discussed in the following sub-sections.

2.7.2. Species and reactions

The chemistry involved in the formation of nitrogen oxides will now be described. The model employed incorporates one of the simplest and most widely used mechanisms for calculations involving nitric oxide formation, namely the Zeldovich mechanism:

$$1. \quad N_2 + O \rightleftharpoons NO + N \tag{34}$$

$$2. \quad O_2 + N \rightleftharpoons NO + O \tag{35}$$

In addition to the above two reactions, the following reactions with the species N_2, O_2, O, H, and OH may be involved in the formation of the oxides of nitrogen, and are considered in the present work:

$$3. \quad N + OH \rightleftharpoons NO + H \tag{36}$$

$$4. \quad H + N_2O \rightleftharpoons OH + N_2 \tag{37}$$

$$5. \quad N_2O + O \rightleftharpoons NO + NO \tag{38}$$

$$6. \quad N_2O + M \rightleftharpoons N_2 + O + M \tag{39}$$

$$7. \quad M + N + O \rightleftharpoons M + NO \tag{40}$$

8. $NO_2 + O \rightleftarrows NO + O_2$ (41)

9. $NO_2 + M \rightleftarrows O + NO + M$ (42)

The choice of these reactions is based on a study of published literature (e.g. Ref. 6). Although some of these reactions have large rate constants, they usually involve species which are present in very small concentrations; hence their contribution towards the formation of nitric oxide is often small compared to that of reactions (1) and (2). Under fuel-rich conditions, reaction (3) may be sigrificant.

2.7.3. The chemical-kinetics equations

The chemical-kinetics equations have been discussed in detail in Ref. 3. These equations are used to determine the concentrations of the pollutant species. Here the equations will be only briefly described. The conservation equation for species j has been given in Section 2.3 (equation 6). Attention is now centred on the source-term in this equation.

The source S_j of species j is the mass rate of creation of species j by chemical reaction and is given by:

$$S_j = \sum_{j=1}^{M} (\alpha'_{ij} - \alpha''_{ij}) (R_j - R_{-j}) \qquad (43)$$

The forward rate, R_j of reaction j, is given by the Arrhenius expression:

$$R_j = 10^{B_j} T^{N_j} \exp(-T_{actj}/T) (\rho\sigma_m)^{\bar{\alpha}_j} \prod_{k=1}^{NS} (\rho\sigma_k)^{(\alpha'_{kj} - \alpha''_{kj})} \qquad (44)*$$

* See nomenclature for explanation of symbols.

The backward rate, R_{-j} of reaction j, is given by a similar expression.

In the calculation of rates of production of N, NO, NO_2, and N_2O by means of the above equations, the concentrations of the other species (which have already been determined by a chemical-equilibrium analysis) are assumed to remain unchanged. The justification for this assumption is that these species are mainly produced by reactions which are considerably faster than those involving NO_x production; therefore, the amounts of these species consumed (or produced) by the NO_x - reactions are negligible. The numerical method of solution of the species-conservation equation (6) is presented in Section 3.6.

2.7.4 Procedure for obtaining chemical-kinetics compositions

The steps for obtaining the concentrations of the species N, NO, NO_2, and N_2O, are:

- The variables u, v, $\tilde{h}$, m_{fu}, m_{ox}, and the mass fractions of the chemical-equilibrium products are first obtained (Section 2.6.4).
- The species-conservation equations are solved to obtain the mass fractions of N, NO, NO_2, and N_2O.
- The mass fraction of nitrogen, m_{N_2}, is adjusted so that all the species mass fractions add to unity.

$$m_{N_2} = 1 - \sum_j m_j, \quad j = 1, \text{NS except for } N_2. \tag{45}$$

3. THE NUMERICAL SOLUTION PROCEDURE

3.1 Introduction

From the preceding sections it is seen that the differential equations under consideration are all non-linear and coupled together. For the flow under consideration there is no possibility for obtaining analytical solutions to them, and numerical methods have to be used. In this case a finite-difference technique is used which combines the main features of the SIMPLE algorithm of Patankar and Spalding (4) and the NEAT algorithm of Spalding (5); these features include:-

- solution of a sufficiently-general single form of differential equations;
- use of pressure and velocities as the main hydrodynamic variables;
- use of the pressure-correction technique for satisfying the continuity equation;
- provision for use of non-uniformly spaced grids;
- use of staggered storage locations for velocities;
- derivation of finite-difference equations by integrating the differential equations over finite control volumes;
- use of an upwind-differencing scheme for convection terms and a central-differencing scheme for diffusion terms;
- enforcing of reciprocity of convection and diffusion fluxes through common walls of adjacent cells;

- line-by-line solution of the finite-difference equations;
- updating of all dependent variables, in sequence, on a line; and
- frequent adjustment of velocities and pressures in order to ensure the satisfaction of overall mass conservation and overall momentum conservation, across sections.

3.2 The finite-difference grid

3.2.1 The cross-stream arrangement

The values of the fluid properties are calculated on a grid of which the nodes lie at constant values of the axial distance x and the radial distance r. Fig. 2 shows how the r-coordinate stretches from the value O at the symmetry axis to the value R at the wall of the duct. Between r=0 and r=R lie NY-2 "grid points", i.e. arbitrarily chosen locations at which the ϕ values are computed; these are indicated by •'s along the base of Fig.2, through which pass vertical full lines. NY is the total number of r nodes, including the boundary values O and R.

Halfway between adjacent pairs of grid points in the range 2 to (NY-1) are drawn vertical broken lines, dividing the whole r range into (NY-2) intervals. The value of any dependent variable ϕ is supposed to be uniform within the interval; the fact is illustrated by the step-like ϕ-distribution of Fig. 2; the horizontals stretch from one broken line to the next.

The ϕ's in these intervals are distinguished by subscripts: ϕ_2, $\phi_3 \cdots \phi_{i-1}$, ϕ_i, $\phi_{i+1} \cdots \phi_{NY-2}$, ϕ_{NY-1}. The boundary values are ϕ_1 and ϕ_{NY}.

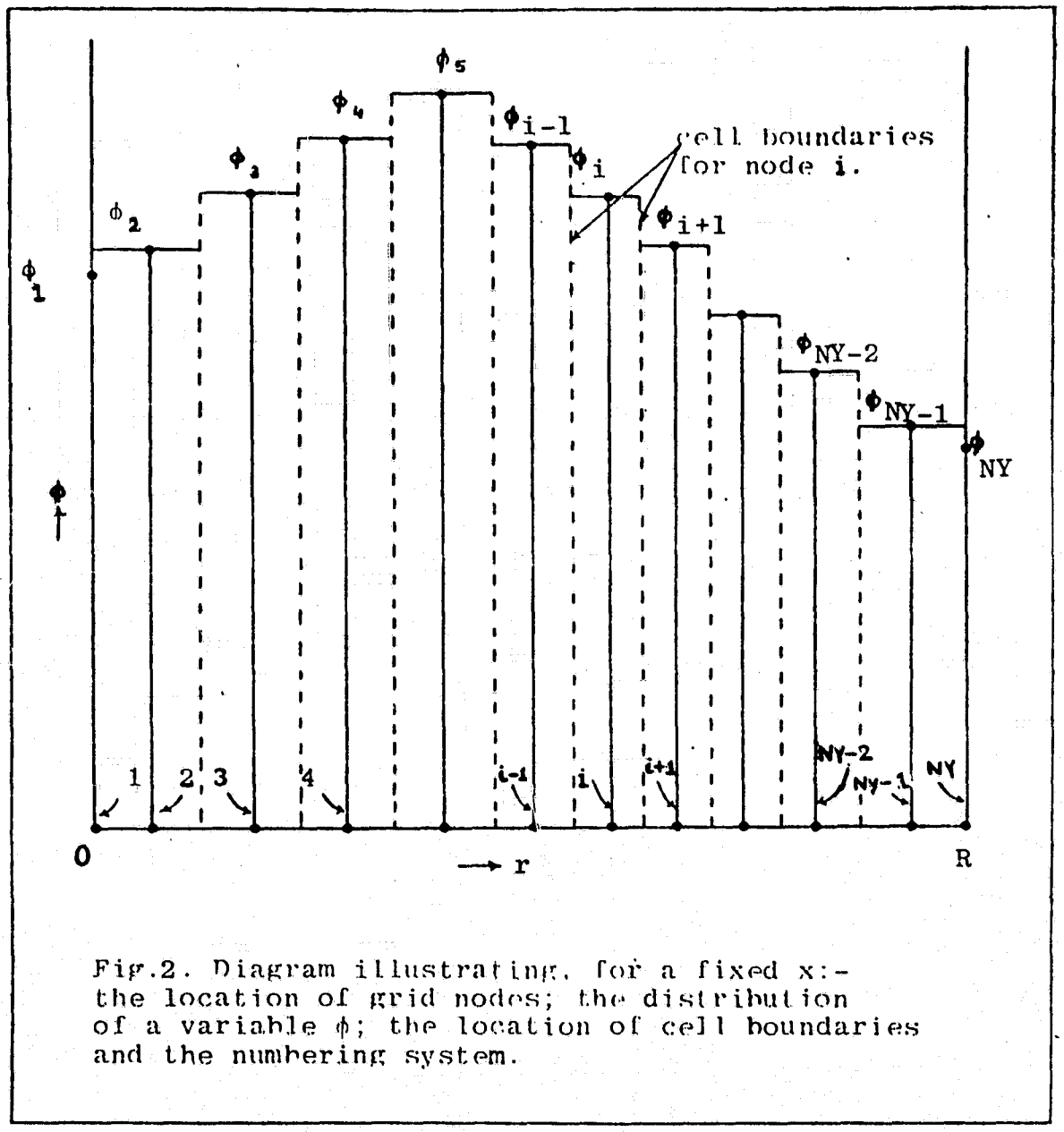


Fig.2. Diagram illustrating, for a fixed x:- the location of grid nodes; the distribution of a variable ϕ; the location of cell boundaries and the numbering system.

3.2.2 The longitudinal grid

The distribution of the longitudinal grid is similar to the cross-stream arrangement. The value of Δx, the increment in x between successive grid nodes, can be varied at will. As is usual in numerical work, small values of Δx (and also Δy) increase accuracy, but also computer time and storage. The right choice always represents a compromise.

3.3 The Finite-Difference Equations

3.3.1 Motive and method

A five-node finite-difference relation will now be derived connecting the value of a dependent variable ϕ_i at a node P with those of:- (a) its two neighbours at the same x-value, ϕ_{i+1} and ϕ_{i-1}; (b) its two neighbours at the same r-value, ϕ_E and ϕ_W. This is to be a linear formula of the form:

$$D_i \phi_i = A_i \phi_{i+1} + B_i \phi_{i-1} + A_E \phi_E + A_W \phi_W + S_u \qquad (46)^*$$

where A_W, A_E, etc., will be treated as constants, the expressions for which are derived by integration of the differential equation (10) over a control volume surrounding the node where ϕ_i prevails. There will be an equation like (46) with individual coefficients, for each grid point, other than those on the boundaries, and for each of the dependent variables, u, v, $\tilde{h}$, m_{fu}, and f.

In equation (46), the ϕ value at the W (upstream) station can be regarded as known. The ϕ values at the E (downstream) station

---

* ϕ_i, ϕ_{i+1}, and ϕ_{i-1} are also alternatively referred to as ϕ_P, ϕ_N, and ϕ_S respectively; A_i and B_i as A_N and A_S respectively.

are regarded as temporarily known, either from the results of a previous iteration, or from an initial 'guess' or estimate. It is therefore useful to combine the last three terms on the right-hand side into one, thus:

$$C_i = A_E \phi_E + A_W \phi_W + S_u \qquad (47)$$

The result is an equation which focusses all the attention on the unknown ϕ's namely:

$$D_i \phi_i = A_i \phi_{i+1} + B_i \phi_{i-1} + C_i \qquad (48)$$

It is now necessary to obtain expressions from which A_i, B_i, C_i and D_i can be evaluated, by integrating the differential equation for ϕ over an appropriate control volume.

3.3.2 Integration over a control volume

Now the integration of the differential equation for ϕ, namely equation (10), over a control volume will be considered. Fig.3(a) illustrates the control volume and its neighbouring ones which must be considered. First, some general remarks are made about the locations of the control volume faces. The two control volumes near the boundaries differ from all the others in that, if the lower edge is denoted by $i-\frac{1}{2}$ and the upper by $i+\frac{1}{2}$:

$$\text{for } i = 2 \quad : \quad r_{i-\frac{1}{2}} = 0; \quad \text{for } i = NY-1 \quad : \quad r_{i+\frac{1}{2}} = R \qquad (49)$$

whereas for all the other control-volume boundaries the appropriate formulae are:

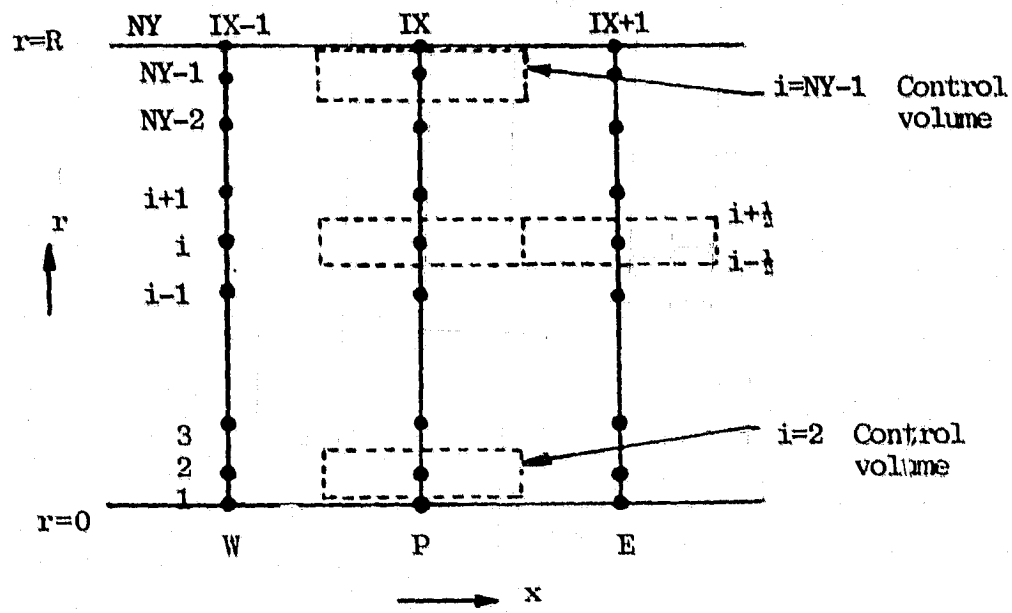


Fig. 3(a). Illustration of part of the x-r grid and of control volumes used for the derivation of the finite-difference equations.

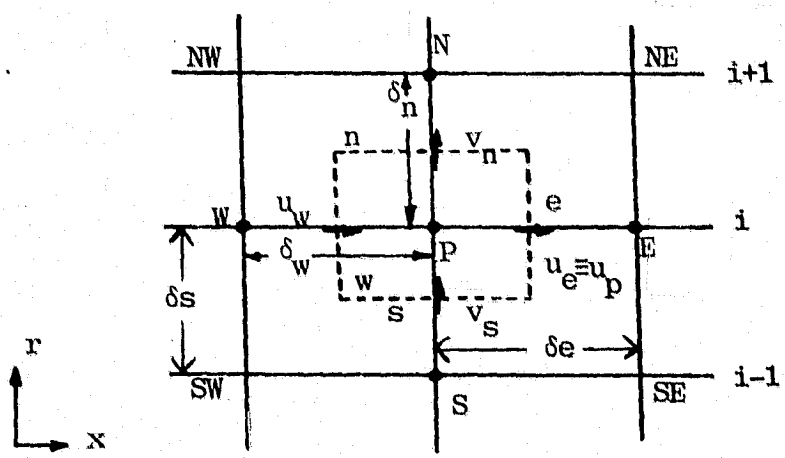


Fig. 3(b). A finite-difference cell around a node P.

$$r_{i-\frac{1}{2}} = \tfrac{1}{2}\,(r_{i-1} + r_i); \quad r_{i+\frac{1}{2}} = \tfrac{1}{2}\,(r_i + r_{i+1}) \tag{50}$$

Similar definitions apply to the grid in the x-direction:

$$\text{for } j=2:\ x_{j-\frac{1}{2}} = 0;\ \text{for } j = NX-1:\ x_{j+\frac{1}{2}} = X \tag{51}$$

where X is the total x-dimension of the integration domain, whereas for all the other control-volume boundaries the appropriate formulae are:

$$x_{j-\frac{1}{2}} = \tfrac{1}{2}\,(x_{j-1} + x_j); \quad x_{j+\frac{1}{2}} = \tfrac{1}{2}\,(x_j + x_{j+1}) \tag{52}$$

With these definitions, it follows that the sum of all the control-volume "heights" and "lengths" equals that of the whole grid; thus:

$$\sum_{i=2}^{NY-1} (r_{i+\frac{1}{2}} - r_{i-\frac{1}{2}}) = R; \quad \sum_{j=2}^{NX-1} (x_{j+\frac{1}{2}} - x_{j-\frac{1}{2}}) = X \tag{53}$$

Thus, if conservation is satisfied for each of the individual control volumes, it will surely also be satisfied for the flow domain.

It is now necessary to apply the ϕ-profile assumption of Fig. 2 and to introduce further assumptions permitting evaluation of the gradients and other terms in equation (10) so as to arrive at expressions for A_i, B_i, C_i and D_i of equation (48).

(a) Diffusion and convection terms

The west face of the cell with area a_w, Fig. 3(b), is first considered. The finite-difference expression for the diffusion flux $J_{diff,\phi,w}$ is given by:

$$a_w J_{diff,\phi,w} = - a_w \Gamma_{\phi,w}\,(\phi_P - \phi_W)/\delta_w \tag{54}$$

where

$$\Gamma_{\phi,w} = \tfrac{1}{2}\,(\Gamma_{\phi,W} + \Gamma_{\phi,P}) \tag{55}$$

The finite-difference expression for the convection flux $J_{conv,\phi,w}$ is given by:

$$a_w J_{conv,\phi,w} = u_w a_w \phi_w \rho_w \tag{56}$$

where

$$\left.\begin{aligned} \phi_w \rho_w &= \phi_W \rho_W \text{ for } a_w u_w \geq o \\ &= \phi_p \rho_p \text{ for } a_w u_w < o \end{aligned}\right\} \tag{57}$$

Expressions (57) are the consequence of the use of an upwind-differencing scheme for the convection terms.

By combining the diffusion and convection fluxes, the total flux through the west cell face, $J_{tot,\phi,w}$ is obtained as:

$$\text{For } C_w \geq o : a_w J_{tot,\phi,w} = (D_w + C_w)\phi_W - D_w \phi_P \tag{58}$$

$$\text{For } C_w < o : a_w J_{tot,\phi,w} = D_w \phi_W - (D_w - C_w)\phi_P \tag{59}$$

In the above expressions:

$$D_w \equiv \Gamma_{\phi,w}\, a_w / \delta_w \tag{60}$$

$$C_w \equiv u_w a_w \rho_w \tag{61}$$

$$\text{and } \rho_w \equiv \rho_W \text{ for } C_w \geq o \quad \equiv \rho_p \text{ for } C_w < o \tag{62}$$

Similarly, for the east cell-face:

$$\text{For } C_e \geq o : a_e J_{tot,\phi,e} = - D_e \phi_E + (D_e + C_e)\phi_P \tag{63}$$

$$\text{For } C_e < o : a_e J_{tot,\phi,e} = - (D_e - C_e)\, \phi_E + D_e \phi_P \tag{64}$$

In the above:

$$D_e \equiv \Gamma_{\phi,e}\, a_e / \delta_e \tag{65}$$

$$C_e \equiv u_e a_e \rho_e \tag{66}$$

$$\left.\begin{aligned} \text{and } \rho_e &\equiv \rho_E \text{ for } C_e < o \\ &\equiv \rho_P \text{ for } C_e \geq o \end{aligned}\right\} \tag{67}$$

Corresponding expressions for the total fluxes may be devised for the north and south cell faces.

Let: $A_W \equiv$ |coefficient of ϕ_W in the expression for $a_w J_{tot,\phi,w}$|

$A_E \equiv$ |coefficient of ϕ_E in the expression for $a_e J_{tot,\phi,e}$| ; etc.

In terms of the D's and C's, these can be conveniently expressed as:

$$A_W = \max (D_w,\ D_w + C_w) \tag{68}$$

$$A_E = \max (D_e,\ D_e - C_e) \quad , \quad \text{etc.} \tag{69}$$

where max (A,B) denotes the larger of A and B.

Then, the volume integral of the LHS of equation (10) may be written as:

$$\iiint_{vol} (\text{LHS of 10})\, dV$$

$$= - a_w J_{tot,\phi,w} + a_e J_{tot,\phi,e} - a_s J_{tot,\phi,s} + a_n J_{tot,\phi,n}$$

$$= \sum_i (A_i\phi_P - A_i\phi_i) - \{C_w - C_e - C_n + C_s\} \qquad (70)$$

where Σ stands for the summation over the four nodes N, E, W and S.

Now, the terms in the curly brackets represent the net mass flow into the cell and should be zero by continuity. Therefore the following equation may be written:

$$\iiint_{vol} (\text{LHS of 10})\, dV$$

$$= \phi_P \sum_i A_i - \sum_i A_i \phi_i \qquad (71)$$

(b) <u>The source term</u>

In general the source term in equation (10) is not zero. Moreover, its composition may vary enormously with different ϕ's and for best results different practices may need to be used for the evaluation of the integral of the source term over the cell volume. Therefore, generally it is assumed that the volume integral can be split into two terms as:

$$\iiint_{vol} S_\phi \, dV = S_u + S_P \, \phi_P \qquad (72)$$

where S_u and S_P are two functions whose composition depends on the particular ϕ considered. If there is no dependence of the integral on ϕ_P, S_P can be put equal to zero.

There are many occasions where it is possible to have several different arrangements for the two functions S_u and S_P. In these cases, a simple rule is to choose an arrangement which gives a negative value to S_P; this helps to promote numerical stability. When the particular ϕ under consideration is known to assume positive values only (e.g. species concentrations), one should in addition try to ensure that S_u is always positive.

(c) Final form of the finite-difference equation

Equating expressions (71) and (72) gives the finite-difference equation for ϕ_P as:

$$\phi_P = \frac{A_W\phi_W + A_E\phi_E + A_N\phi_N + A_S\phi_S + S_u}{(A_W + A_E + A_N + A_S) - S_P} \qquad (73)$$

In the above equation the A's are given by:

$$A_W = \max (D_w, D_w + C_w) \qquad (74)$$

$$A_E = \max (D_e, D_e - C_e) \qquad (75)$$

$$A_N = \max (D_n, D_n - C_n) \qquad (76)$$

$$A_S = \max (D_s, D_s + C_s) \qquad (77)$$

The D's and C's in the above equations are given by:

$$D_w \equiv \tfrac{1}{2} (\Gamma_{\phi,W} + \Gamma_{\phi,P})\, a_w/\delta_w \tag{78}$$

$$D_e \equiv \tfrac{1}{2} (\Gamma_{\phi,E} + \Gamma_{\phi,P})\, a_e/\delta_e \tag{79}$$

$$D_n \equiv \tfrac{1}{2} (\Gamma_{\phi,N} + \Gamma_{\phi,P})\, a_n/\delta_n \tag{80}$$

$$D_s \equiv \tfrac{1}{2} (\Gamma_{\phi,S} + \Gamma_{\phi,P})\, a_s/\delta_s \tag{81}$$

$$C_w \equiv a_w u_w \rho_w \tag{82}$$

$$C_e \equiv a_e u_e \rho_e \tag{83}$$

$$C_n \equiv a_n v_n \rho_n \tag{84}$$

$$C_s \equiv a_s v_s \rho_s \tag{85}$$

It is worth remarking that the A's are always positive; this has been ensured by the use of upwind differencing in the convection terms.

Later it will be shown that staggered locations for the velocities will be used. In accordance with this, velocities are actually stored at locations marked by arrows in Fig. 3; in this case the velocities will be referred to by capital subscript according to the following:

$$u_e \equiv u_P \; ; \; u_w = u_W \; ; \; v_n \equiv v_P \text{ and } v_s \equiv v_S$$

The u-velocities are stored on the east face of the continuity cell and v-velocities on the north face of the cell.

3.3.3 The momentum equations

The finite-difference momentum equations have the same final form as that for the general ϕ equation, viz. equation (73). However, in the derivation of the equation, two differences in practice may be identified. Firstly, different finite-difference cells are used. This arises because of the adoption of staggered storage locations for the velocity components. Thus, the finite-difference equation for u is derived by integrating the x-momentum equation over the cell shown in Fig. 4(a). This cell is formed by two adjacent constant x-grid lines and two lines drawn mid-way between adjacent constant-r grid lines. A different but similarly constructed cell is used for v, as shown in Fig. 4(b).

The second difference lies in the way the diffusion and convection terms (i.e. D_e, D_w, C_e, C_w) through the cell faces are evaluated. These terms, for a velocity cell, are all obtained from those for the ϕ cells which overlap the particular velocity cell in question. Thus, the term, diffusion or convection, through the west face of the u cell, Fig. 4(a), is obtained as the arithmetic mean of the corresponding fluxes through the west and east faces of the continuity cell enclosing the node P, i.e. for a u cell (Figure 4(a)),

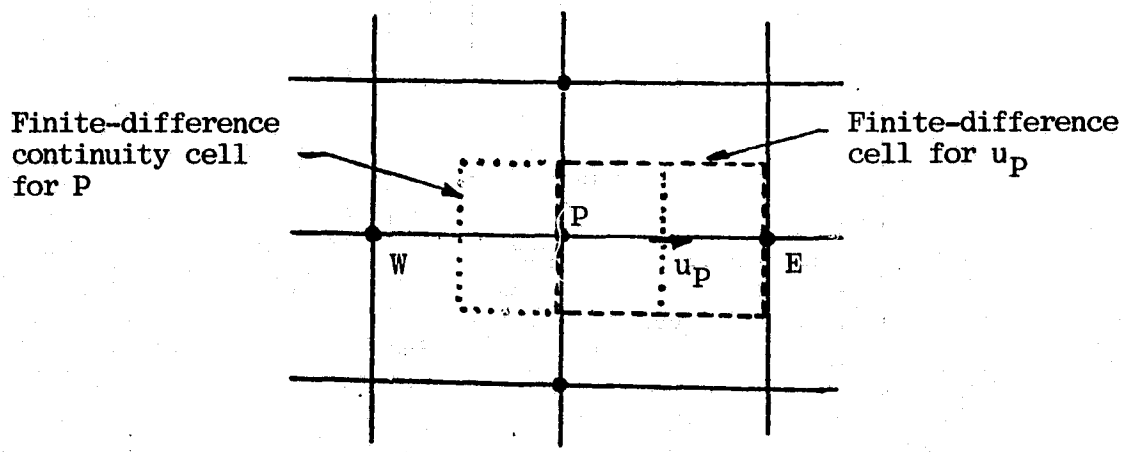
$$A_W = \max \{\tfrac{1}{2}(D_e + D_w),\ \tfrac{1}{2}(D_e + D_w) - \tfrac{1}{2}(C_e + C_w)\} \qquad (86)$$

$$A_E = \max \{\tfrac{1}{2}(D_{ee} + D_e),\ \tfrac{1}{2}(D_{ee} + D_e) - \tfrac{1}{2}(C_{ee} + C_e)\} \qquad (87)$$

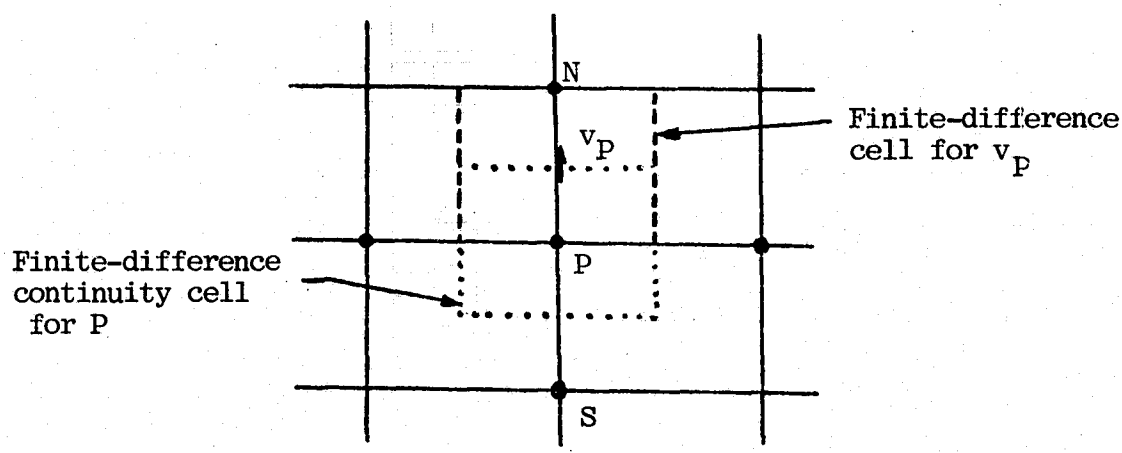
C_{ee} = convection flux through the east face of the continuity cell surrounding node E (Fig. 4(a)).

D_{ee} = diffusion flux through the east face of the continuity cell surrounding node E (Fig. 4(a)).

Exactly similar procedures are adopted for the other cell faces and for the v-cells. This practice offers two main advantages: computational simplicity, and, more consistent satisfaction of the conservation principle for the different types of cells.



(a) A u-cell



(b) A v-cell

Fig. 4: Diagrams illustrating the finite-difference cells for the component velocities.

3.3.4 The pressure-correction equation

A special practice is adopted for the solution of the continuity equation. The sequence is as follows:

(i) Using an estimated (or previous iteration) pressure field p*, the x- and r-momentum finite-difference equations are solved. This gives a first approximation to the velocity field (designated the'starred'velocity field, u* and v*). This field in general does not satisfy the continuity equation.

(ii) Correction u', v' and p' to the starred velocity field (u*, v*) and the estimated pressure field p* are derived from the continuity equation. These corrections are added to the starred fields:

$$u = u^* + u' \tag{88}$$

$$v = v^* + v' \tag{89}$$

$$p = p^* + p' \tag{90}$$

This results in a velocity field which is in local continuity balance.

(iii) In addition to the above steps, block adjustment techniques are used at intermediate stages (see Sec. 3.8) in order to obtain integral mass and momentum balances.

The derivation of the equations for the corrections u', v', and p' will now be considered.

Figure 3(b) shows a cell around the node P together with the velocities crossing its four faces. The velocity u_p is corrected for continuity using a correction u'_p which is assumed to result from changes of pressure at locations on both sides of it, i.e.

p'_P and p'_E, according to:

$$u'_P = \frac{\partial u_P}{\partial p_P} p'_P + \frac{\partial u_P}{\partial p_E} p'_E \qquad (91)$$

Now, the finite-difference equation for u_P can be written as (general form being equation (73)):

$$(\sum_i A_i - S_P) u_P = \sum_i A_i u_i + \{a_e(p_P - p_E) + S'_u\} \qquad (92)$$

where $\sum_i$ denotes the summation over the four neighbouring nodes N, E, W and S; the S_u component of the source term has been split into the terms inside the curly brackets to show the pressure-gradient term explicitly; and a_e is the area of the east cell-face. Assuming that all the coefficients in (92) are not affected by changes in the p's:

$$u'_P = (\frac{a_e}{D_P}) (p'_P - p'_E) \qquad (93)$$

where $D_P = \sum_i A_i - S_P$ (94)

Other velocity corrections can be derived similarly.

By requiring the satisfaction of continuity (i.e.equation (5) integrated over a ϕ cell),

$$a_e\rho_e (u^*_P + u'_P) - a_w\rho_w (u^*_W + u'_W) + a_n\rho_n (v^*_P + v'_P) -$$

$$- a_s\rho_s (v^*_S + v'_S) = 0 \qquad (95)$$

where ρ_w and ρ_e are as defined in equations (62) and (67); ρ_n and ρ_s are similarly defined.

By substituting velocity correction equations, such as (93), for u'_P, u'_W, v'_P and v'_S into equation (95) an equation for the pressure-correction p' is obtained. The equation will have the standard form, i.e.:

$$D'_P \, p'_P = \sum_i A_i p'_i + S_u \qquad (96)$$

where $\sum_i$ denotes summation over the four neighbouring nodes.

Thus the above equation can be solved by the same techniques as used for all the other finite-difference equations.

3.3.5 Section-wise momentum balance

During the solution of the momentum and continuity equations, section-wise momentum balances are performed in order to procure integral conservation of momentum across the strip of finite-difference cells currently being solved for. The procedure is termed as SNIP i.e. Start the momentum equations with a New Integration for Pressure, since it provides a starting guess of the pressure field (i.e. the p* field of Sec. 3.3.4) for the solution of the momentum equations.

The procedure consists in adding up all the terms of the x-momentum finite-difference equation along a line of constant x and making this sum zero by block adjustment of pressure. The formula for the adjustment of pressure is obtained from the x-momentum finite-difference equation (92) as:

$$\Delta \overline{p} = - \frac{\sum_j \left[\sum_i (A_i - S_p) u_p - \sum_i A_i u_i - S'_u \right]}{\text{(Total area of strip normal to the x-direction)}} \qquad (97)$$

where $\sum_j$ denotes the summation over all cells at the x-location under consideration and $\sum_i$ denotes the summation over the four

neighbouring nodes.

It should be noted that $\Delta\overline{p}$ is added to all pressures downstream of the column of cells under consideration. An option is provided for the user to switch the above procedure off by setting the index ISNIP=1.

3.4 Solution of the finite-difference equations

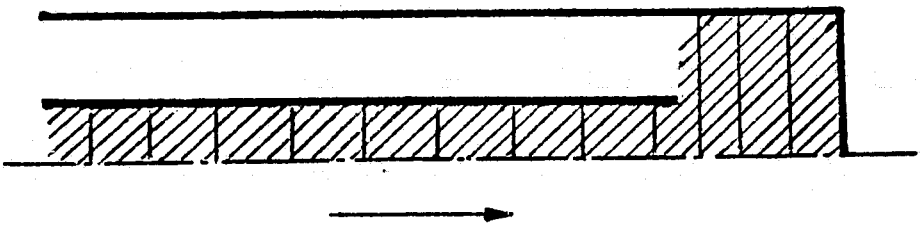
3.4.1 Solution procedure

The numerical procedure used to solve the finite-difference equations is an iterative one, requiring the flow field to be swept repeatedly until termination, either through having satisfied the convergence test, or through some other control.

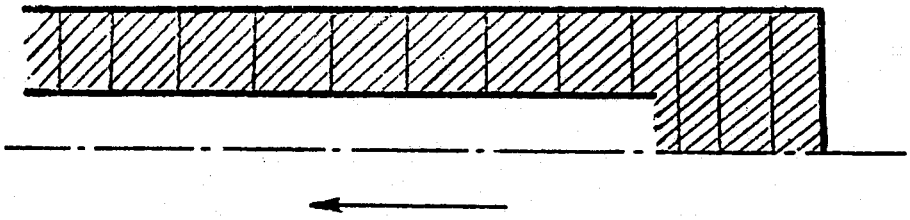
In a sweep of the field, strips of finite-difference cells along constant-x grid lines are considered, one by one; hence the procedure progresses line-by-line. The extent of the field covered during forward and reverse marches is shown in Fig. 5. At each line, all the dependent variables are considered, one after another, and, for each variable, finite-difference equations are set up, one for each of the cells on the line, Fig. 6. These finite-difference equations are solved before the next variable is considered. Thus, the equation set, dealt with each time, consists of the finite-difference equations for all the cells along a grid line. Since all the finite-difference equations have the same general form of (73), the equation for one of the variables ϕ can be written as:

$$\phi_i \left(\sum_i A_{ij} - S_{pj}\right) = \sum_i A_{ij}\phi_i + S_{uj} \qquad (98)$$

In the above equation the subscript j refers to the cell on the jth constant -r grid line ; ϕ_j is normally calculated for all the control cells in the line viz. from, j=2, to j=N-1. The values for j equal to 1 and N are the boundary values, which must be specified, while the other values ϕ on the line are



(a) Forward March



(b) Reverse March

Fig. 5: The extent of the field covered by the cross-stream TDMA during forward and reverse marches.

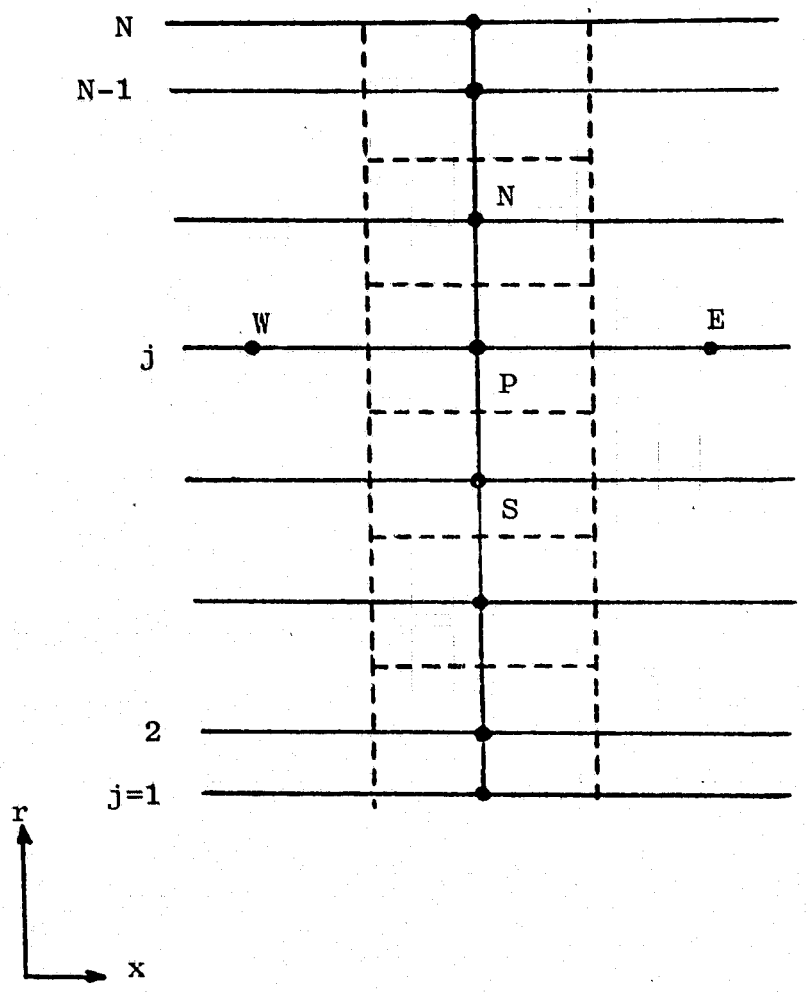


Fig. 6: Diagram illustrating a typical strip of cells along a constant-x grid line.

calculated. Symbol Σ_i denotes the sum over the four neighbour nodes of j.

The above set of equations (98) which has to be solved for the unknown ϕ's is of a form which enables the solution to be obtained using the well-known tri-diagonal matrix algorithm (TDMA). Details of this method may be found, for example in Ref. 1.

3.4.2 Under-relaxation

The solution procedure described above involves the solution of the finite-difference equations which are expressed in a linearised form. However the equations are not truly linear; therefore, an iterative solution procedure is required to continually update the coefficients until a converged solution is obtained. If the changes in the values of the variables from one iteration to the next are large, there is a possibility that convergence may not be achieved at all. To keep these changes sufficiently small, the dependent variables are suitably under-relaxed. Two forms of under-relaxation are described below.

(a) Inertial under-relaxation

The central idea in inertial under-relaxation is to under-relax the variables selectively at those locations where the source term in the equation is large compared to the convection and diffusion terms. At such locations, changes in the source term produce large changes in the variable, which may then result in divergence. Inertial under-relaxation limits the changes in the variable by imposing a gradual change in the source term. This is achieved by adding a term $a(\phi^o-\phi_p)$ to the source term, where ϕ^o is the previous iteration value of ϕ_p and 'a' is a constant. The additional term has the opposite sign of the changes to the source term; and it therefore diminishes the extent to which the source term is changed.

When convergence is achieved $\phi^o \to \phi_p$, the additional term tends to zero; and therefore the solution obtained is the solution of the original equation. The calculation of the constant 'a' will now be described.

Consider, for example, that the changes in ϕ between successive iterations should be restricted to 5 per cent,

i.e. $$\left|\frac{\phi_p - \phi^o}{\phi^o}\right| = 0.05 \qquad (99)$$

For small $\sum_i A_i\phi_i$ the finite-difference equation (73) for ϕ_p can be approximated by:

$$(\sum_i A_i - S_p)\, \phi_p \approx S_u \qquad (100)$$

If S_u^o is the previous iteration value of S_u corresponding to ϕ^o, and assuming $(\sum_i A_i - S_p)$ to remain approximately constant,

$$(\sum_i A_i - S_p)\, (\phi_p - \phi^o) \approx S_u - S_u{}^o \qquad (101)$$

The additional term $a(\phi^o - \phi_p)$ is added to the right-hand side of this equation giving:

$$(\sum_i A_i - S_p)\, (\phi_p - \phi^o) \approx (S_u - S_u{}^o) + a(\phi^o - \phi_p) \qquad (102)$$

Therefore, from equations (99) and (102),

$$a + (\sum_i A_i - S_p) \approx 20\, (\frac{S_u - S_u{}^o}{\phi^o}) \qquad (103)$$

Since $(\sum_i A_i - S_p)$ is usually small compared to a,

$$a \approx \frac{20\ (S_u - S_u^{o})}{\phi^{o}} \qquad (104)$$

This value of 'a' will limit changes in ϕ_p to 5 per cent. When oscillations or divergence are being observed, it is necessary to increase the value of 'a'. However, care is to be taken to see that the solution is not 'frozen' by excessive under-relaxing.

In the present work inertial under-relaxation is employed only for the u- and v-velocities, since experience has shown that it is not necessary to under-relax the other variables.

(b) Use of an under-relaxation factor

The second method of under-relaxation is to consider the value of ϕ to be a weighted mean of its current-iteration and previous-iteration values.

This method is employed only for pressure and amounts to modifying equation (90) as:

$$p = p^* + \alpha_p\, p' \qquad (105)$$

where α_p the under-relaxation factor lies between 0 and 1.

3.5 Solution of the Chemical-Equilibrium Equations

3.5.1 Solution procedure

The chemical-equilibrium equations were discussed in Section 2.6. They are solved by the procedure given in Ref. 2. The salient features of this technique are described next.

The Newton-Raphson iteration method is used to solve the equilibrium equations. The correction variables are (NLM + 2) in number, where NLM is the number of distinct elements in the system being considered (there are three in the present case, i.e. C, O, and H). The corresponding correction equations are obtained after appropriate linearization as follows.

(a) The correction equations for the conservation of elements are expressed in terms of the non-dimensionalized Lagrange multipliers, π_i as:

$$\sum_{i=1}^{NLM}\left(\sum_{k=1}^{NSE} a_{ik}^{L} a_{jk}^{L}\sigma_k\right)\pi_i + \left(\sum_{k=1}^{NSE} a_{jk}^{L}\sigma_k\right)\Delta\log\sigma_m$$

$$+\left\{\sum_{k=1}^{NSE} a_{jk}^{L}\sigma_k\left(\frac{h_k}{RT}\right)\right\}\Delta\log T = \sum_{k=1}^{NSE} a_{jk}^{L}\sigma_k\left(\frac{g_k}{RT}\right),\ j=1,\ NLM \qquad (106)$$

(b) The correction equation for the reciprocal of the mixture molecular weight, σ_m is:

$$\sum_{i=1}^{NLM}\left\{\sum_{k=1}^{NSE} a_{ik}^{L}\sigma_k\right\}\pi_i + \left\{\sum_{k=1}^{NSE}\sigma_k - \sigma_m\right\}\Delta\log\sigma_m$$

$$+\left\{\sum_{k=1}^{NSE}\sigma_k\left(\frac{h_k}{RT}\right)\right\}\Delta\log T = \sigma_m - \sum_{k=1}^{NSE}\sigma_k + \sum_{k=1}^{NSE}\sigma_k\left(\frac{g_k}{RT}\right) \qquad (107)$$

(c) The correction equation for temperature is based on an enthalpy balance condition (i.e., enthalpy of the products is specified) and is:

$$\sum_{i=1}^{NLM}\left\{\sum_{k=1}^{NSE} a_{ik}^{L}\sigma_k\left(\frac{h_k}{RT}\right)\right\}\pi_i + \left\{\sum_{k=1}^{NSE}\sigma_k\left(\frac{h_k}{RT}\right)\right\}\Delta\log\sigma_m$$

$$+ \left\{ \sum_{k=1}^{NSE} \sigma_k \left(\frac{C_{pk}}{R}\right) + \sum_{k=1}^{NSE} \sigma_k \left(\frac{h_k}{RT}\right)^2 \right\} \Delta \log T$$

$$= \frac{h_{pr}}{RT} - \sum_{k=1}^{NSE} \sigma_k \left(\frac{h_k}{RT}\right) + \sum_{k=1}^{NSE} \sigma_k \left(\frac{h_k}{RT}\right) \left(\frac{g_k}{RT}\right) \qquad (108)$$

where h_{pr} is the enthalpy (sensible & chemical) of the equilibrium-products and is obtained from equation (32).

The correction equations (106), (107), (108) involve the unknowns π_i (i=1, NLM), $\Delta \log \sigma_m$, and $\Delta \log T$. They are solved by a standard Gaussian elimination procedure. The correction matrix will become singular at the solution point when the coefficient of $\Delta \log \sigma_m$ in equation (107) is identically zero. This potential singularity is avoided by a single interchange between the row involving the zero coefficient of $\Delta \log \sigma_m$ and any other row (in practice, the row with the largest coefficient of $\Delta \log \sigma_m$ is selected.) All other diagonal elements are positive and do not require special treatment.

The new values of the variables are then obtained as:

$$\Delta \log \sigma_k = \left(\frac{h_k}{RT}\right) \Delta \log T - \left(\frac{g_k}{RT}\right) + \Delta \log \sigma_m + \sum_{i=1}^{NLM} a_{ik}^L \pi_i, \quad k=1, NSE \qquad (110)$$

$$\log \sigma_i^{(k+1)} = \log \sigma_i^{(k)} + \eta (\Delta \log \sigma_i)^{(k)}, \quad i=1, NSE \qquad (111)$$

$$\log \sigma_m^{(k+1)} = \log \sigma_m^{(k)} + \eta (\Delta \log \sigma_m)^{(k)} \qquad (112)$$

$$\log T^{(k+1)} = \log T^{(k)} + \eta (\Delta \log T)^{(k)} \qquad (113)$$

where the superscripts indicate the iteration number, and η is an under-relaxation parameter ($0<\eta\leq 1$). The determination of η and the convergence criterion are discussed in Section 3.5.3.

3.5.2 Initial estimate of species mole-numbers and temperature

The initial estimate of the species mole-numbers is based on complete stoichiometric combustion. Thus if x and y are the number of kg-atoms of carbon and hydrogen respectively, per kg of mixture, the initial estimate is given by:

$$\sigma_{CO_2} = x \tag{114}$$

$$\sigma_{H_2O} = y/2 \tag{115}$$

All other mole numbers are set equal to a small number 10^{-6}.

The initial estimate for temperature is obtained from an adiabatic enthalpy balance for the assumed composition and the given mixture enthalpy. The procedure is the same as that described in Section 3.7.

3.5.3 Under-relaxation and convergence criterion

The self-adjusting under-relaxation parameter η similar to that of Ref. 2 is used here. This parameter is determined at each iteration from:

$$\eta = \text{minimum of } (1, \eta_1, \eta_2) \tag{116}$$

where η_1 and η_2 are quantities which are defined below.

(a) For T, σ_m, and species with $(\sigma_i/\sigma_m) > 10^{-8}$ and $\Delta\log\sigma_i > 0$, η_1 is defined as:

$$\eta_1 \equiv \frac{0.2}{\max\left(|\Delta\log T|, |\Delta\log\sigma_m|, |\Delta\log\sigma_i|\right)} \tag{117}$$

This causes the correction of the variables T, σ_m, and σ_i to be scaled so that none of the variables is increased by more than a factor of 1.22 (=exp(0.2)) on any one iteration. This is different from the definition of η_1 in Ref 2, which permits maximum increases by a factor of up to 7.39 (=exp(2)) on any one iteration.

(b) For species with $(\sigma_i/\sigma_m) < 10^{-8}$ and $\Delta\log\sigma_i > 0$, η_2 is defined as:

$$\eta_2 \equiv \left| \frac{\log(10^{-4}) - \log(\sigma_i/\sigma_m)}{\Delta\log\sigma_i - \Delta\log\sigma_m} \right| \tag{118}$$

This scales all the corrections so that the species with σ_i initially less than 10^{-8} increase to no more than 10^{-4}.

A convergence criterion similar to that recommended in Ref. 2. is used. This is:

$$\left(\frac{\sigma_i}{\sigma_m}\right) |\Delta\log\sigma_i| \leq 1.0\times10^{-10}, \quad i=1, \text{NSE} \tag{119}$$

and

$$|\Delta\log\sigma_m| \leq 1.0\times10^{-10} \tag{120}$$

3.5.4 Polynomial fits for equilibrium-product-species concentrations

The equilibrium compositions are represented in terms of polynomials of enthalpy at different pressures. The polynomial coefficients are determined in computations external and prior to the main computer code. The steps for obtaining these polynomials are now described.

The equilibrium compositions are computed by the method of Section 3.5.1 for several values of enthalpy at different pressures. At a given pressure, the logarithm of the equilibrium-species mass fraction is represented as a polynomial of enthalpy. There are two distinct polynomials (one over each of two ranges of enthalpy), both of third order, for each of the species. The logarithm of the species mass fraction is used since the variation in mass fraction over the enthalpy range is a few orders of magnitude (for species like O, H, OH etc.). In the main code, when the equilibrium composition is required for a particular enthalpy and pressure the polynomials are used to calculate the species mass fractions.

3.6 Solution of the Chemical-Kinetics Equations

3.6.1 Solution procedure

The chemical-kinetics equations were discussed in Section 2.7. They are solved by the procedure described in Ref. 3; it will be only briefly described here.

The procedure involves a point-by-point simultaneous solution of all the pollutant concentrations (i.e. N, NO, NO_2, and N_2O). The line-by-line procedure which is used to solve for other dependent variables (u, v, $\tilde{h}$, f, and m_{fu}) is not suitable for the solution of the chemical-kinetics equations. The reason is that

the concentration of any pollutant species at a point depends more strongly on the concentrations of the other pollutant species at the same point rather than its own concentration at neighbouring points. The line-by-line procedure would, under such conditions, require an excessively large number of iterations to achieve convergence (e.g. Ref.3).

The Newton-Raphson method is used to solve the chemical-kinetics equations. The correction equations for the species mole numbers are expressed, after appropriate linearization as:

$$\sum_{k=1}^{NSK} \{A_p \sigma_i \delta_{ik} + \sum_{j=1}^{M} (\alpha'_{ij} - \alpha''_{ij})(R_j \alpha'_{kj} - R_{-j} \alpha''_{kj}) \Delta\log\sigma_k\}$$

$$= A_p(\sigma_i^* - \sigma_i) - \sum_{j=1}^{M} (\alpha'_{ij} - \alpha''_{ij})(R_j - R_{-j}), \quad i=1, NSK \qquad (121)$$

Equations (121) involve the unknowns $\Delta\log\sigma_k$ (k=1,NSK). The equations are solved by a standard Gaussian elimination procedure. All the diagonal elements of the correction matrix are positive, so that no matrix conditioning is necessary.

The new values of the variables are then obtained as:

$$\log\sigma_i^{(k+1)} = \log\sigma_i^{(k)} + \eta(\Delta\log\sigma_i)^{(k)}, \quad i=1, NSK \qquad (122)$$

where the subscripts indicate the iteration number and η is an under-relaxation parameter ($0<\eta\leq 1$). The determination of η, and the convergence criterion, are discussed below.

3.6.2 Initial estimate of the mole numbers of pollutant species

The initial estimate is obtained by setting the concentrations of the pollutant species at any grid node equal to those at the corresponding upstream node. For the very first set of cross-stream points, the initial estimates of the concentrations are set to a small number, 10^{-15} to 10^{-20}. This procedure is followed when sweeping through the integration domain for the first time. For subsequent sweeps, the values at the particular grid node from the previous sweep are used as the initial estimates for the solution of the correction equation (121).

3.6.3 Under-relaxation and convergence criterion

The self-adjusting under-relaxation parameter of Ref. 2 is used without modification (see also Section 3.5.3). The solution at any grid node is assumed to have converged when the concentrations of the NO_x-species remain within a certain value from one iteration to the next.

3.7 Solution of the Auxiliary Equations

The auxiliary equations were discussed in Section 2.5. Of these only the equations dealing with the temperature of the mixture require an iterative solution procedure; the other equations involve straightforward algebraic expressions. All heat transfer effects affect the enthalpy equation which in turn affects the fluid temperature according to equation (146) of Section 5.2.

The temperature equation (26) is solved by the Newton-Raphson iteration method. The Newton-Raphson correction equation for temperature is:

$$h - \sum_{j=1}^{NS} m_j h_j (T_k) = \left(\sum_{j=1}^{NS} C_{pj} (T_k)\, m_j \right) \Delta T_k \qquad (123)$$

$$T_{k+1} = T_k + \Delta T_k \qquad (124)$$

where T_k ≡ the temperature at the k^{th} iteration

$h_j(T_k)$ ≡ the enthalpy of species j at temperature T_k

$C_{pj}(T_k)$ ≡ the constant pressure specific heat of species j at temperature T_k (see Section 5.2).

Convergence is monitored by computing $|\Delta T_k/T_{k+1}|$ at each iteration; and, when its value falls below a prespecified limit, the iteration is terminated.

3.8 Summary of the solution procedure

Now that the main features of the finite-difference solution procedure have been described, it will be useful to summarize the main steps involved:

(1) At the start u_1's and ϕ_o's are known (Fig.7); if this strip of cells is at the boundary the u_1's and ϕ_o's are known from the boundary conditions; otherwise they are known from the solution at the previous strip. The p_2's are 'guessed' (see step 8). The problem is then to determine u_3's, v_2's, p_2's, and ϕ_2's.

(2) The u_3's are guessed so as to satisfy overall continuity for the strip. The p_4's are then estimated (based on the guessed p_2's) so that overall momentum is satisfied for the strip, with assumed u_3's.

(3) The x-momentum finite-difference equation is solved for u_3's.

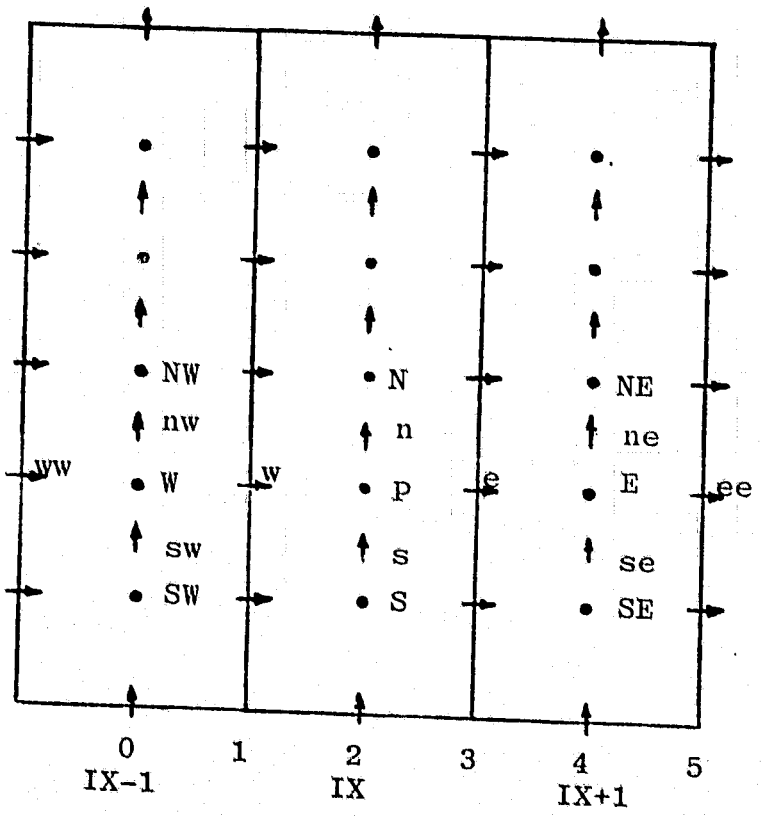


Fig. 7: Diagram illustrating the solution sequence.

(4) Overall continuity is checked at Section 3 and the u_3's obtained in Step (3) are all adjusted by a uniform amount to satisfy overall continuity.

(5) The r-momentum finite-difference equation is solved for v_2's.

(6) The finite-difference equations for all other variables ϕ are solved to obtain the ϕ_2's.

(7) Continuity imbalances for individual cells at 2 are checked and the pressure-correction equation is solved; corresponding adjustments are then made to u_3's, v_2's and p_2's. This results in u_1's, v_2's and u_3's being in overall and local continuity balance.

(8) Finally, the p_4's are adjusted by a uniform amount (as in Step 2) to ensure overall momentum satisfaction for the strip. These p_4's are used as the 'guessed' values for the solution at the next strip.

(9) The solution then advances in the x-direction to the next strip. This continues until the whole flow domain has been swept.

(10) These sweeps are repeated until convergence is achieved. Facility is also provided to repeat the solution at a given line (i.e. perform iterations at a line). These iterations are terminated when the residues in all the equations being solved fall below a prespecified small value; or when the number of iterations exceeds a prespecified maximum value.

4. FURTHER FEATURES OF THE CALCULATION PROCEDURE

4.1 The Treatment of Wall Boundaries

The wall boundaries are treated by including the wall shear stress in the equation for the velocity parallel to the wall; and by setting the velocity at the wall to zero (the no-slip condition). The treatment is similar to that employed in References 7 and 10.

The wall shear stress τ is given by:

$$\tau = s\,(\rho u^2)_{NW} \tag{125}$$

where the subscript NW refers to the near-wall node.

The quantity s is the shear-stress coefficient and is given by (Reference 7):

$$s^{\frac{1}{2}} = \frac{\kappa}{\ell n\,(ERs^{\frac{1}{2}})} \tag{126}$$

where E = constant (taken to be 9.0);
κ = von Karman constant (taken to be 0.435);
R = Reynold's number = $(\rho u \Delta y/\mu_\ell)_{NW}$;
Δy = distance of wall from the near-wall node;
μ_ℓ = laminar viscosity.

The shear stress is incorporated into the finite-difference equations by linearization of the term ρu^2 as $\rho|u|u$. Details may be found in Reference 7. In order to solve eq. (126) for s, a value of s is guessed and substituted in the RHS of eq. (126) to give a better estimate of s. The process is repeated until the values of s from one step to the next remain within 0.01%.

4.2 The Treatment of the Inner Wall

The effect of the inner wall is introduced by modifying the source terms of the u-momentum equation at the nodes adjacent to the inner wall. The source-term modification is done to include the effects of the wall shear stress as per the discussion of Section 4.1.

4.3 The Treatment of Heat Transfer

4.3.1 Heat Transfer processes considered

In this section the inclusion of heat transfer effects into the solution procedure is described. These effects enter as boundary conditions in the stagnation enthalpy equation. The following modes of heat transfer are considered in the present work:

(i) convective heat transfer from hot combustion gases to passage walls;
(ii) convective heat transfer from hot walls to colder inlet fuel-air mixture;
(iii) axial wall conduction;
(iv) wall to wall radiation;
(v) free and forced convection from outer wall to surroundings;
(vi) radiation from outer wall to surroundings.

The radiant heat exchange between the flame and the walls is ignored since the methane-air flame has a low emissivity and since the mean beam length in the present case is small.

The inclusion of the heat transfer effects involves appropriate modifications of the source terms in the stagnation enthalpy equation at the inner and outer tube walls and at the end wall. These are described below.

4.3.2 Heat transfer at the inner tube wall

The heat transfer effects at the inner tube wall are introduced by modifying the source terms for the finite-difference cells at N, P, and S (Fig. 8) at the x-location currently being solved for. The various heat transfer processes are considered individually below.

(i) Heat transfer between wall and gases:

For heat transfer between N and P, the overall heat transfer coefficient $U_{1,0}$ is given by (Ref. 11):

$$\frac{1}{r_{1,0}U_{1,0}} = \frac{1}{r_{1,0}h_{1,0}} + \frac{\ell n(r_{1,0}/r_P)}{k} \qquad (127)$$

where k is the conductivity of the wall material (stainless steel) and $h_{1,0}$ is the convection heat transfer coefficient.

For heat transfer between S and P, the overall heat transfer coefficient $U_{1,i}$ is given by:

$$\frac{1}{r_{1,i}U_{1,i}} = \frac{1}{r_{1,i}h_{1,i}} + \frac{\ell n(r_p/r_{1,i})}{k} \qquad (128)$$

In the above equations, $h_{1,i}$ and $h_{1,0}$ are calculated from prescribed Stanton numbers $St_{1,i}$ and $St_{1,0}$:

$$h_{1,i} = St_{1,i}\,\rho_S|U_S|C_p \qquad (129)$$

$$h_{1,0} = St_{1,0}\,\rho_N|U_N|C_p \qquad (130)$$

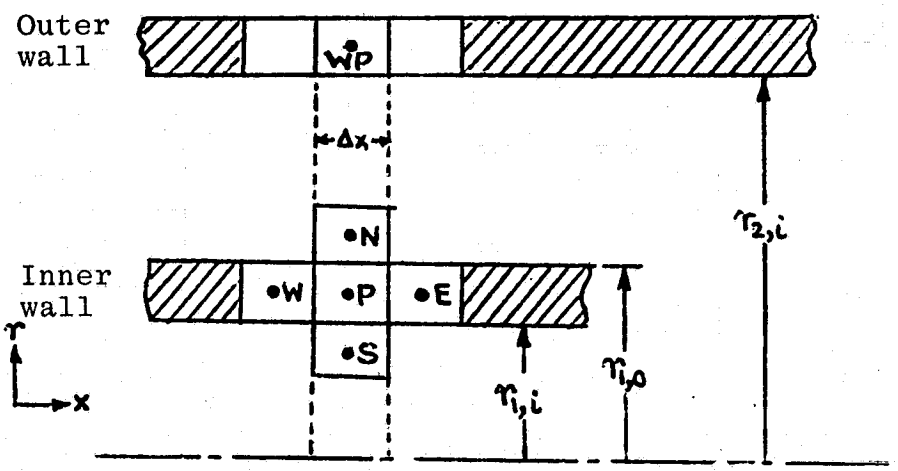


Fig. 8: Heat transfer calculation at inner tube wall.

where U_S and U_N are the velocities parallel to the wall at S and N respectively; and ρ is the density.

The values of the Stanton numbers in equations (129) and (130) are assumed to be 0.003, which in the authors' experience is typical of the flow situation being considered*.

The specific heat C_p appearing in the above equations is assumed to be constant (=1100 J/Kg.^{o}K). It should be noted that it is possible to calculate C_p from the local values of temperature and composition, but in view of the other approximations involved, it is not worth going into this complication.

Finally, the heat fluxes are included in the finite-difference equations by augmenting the source terms of the enthalpy equation at nodes N, P, and S as:

$$Su_N = Su_N + U_{1,0}r_{1,0}\Delta x(T_P-T_N) \quad (131)$$

$$Su_P = Su_P + U_{1,0}r_{1,0}\Delta x(T_N) + U_{1,i}r_{1,i}\Delta x(T_S) \quad (132)$$

$$SP_P = SP_P - U_{1,0}r_{1,0}\Delta x - U_{1,i}r_{1,i}\Delta x \quad (133)$$

$$Su_S = Su_S + U_{1,i}r_{1,i}\Delta x(T_P-T_S) \quad (134)$$

(ii) Axial wall conduction

This is included in the finite-difference form of the enthalpy equation by modifying the source term at point P as:

$$Su_P = Su_P + \frac{k\Delta A}{\Delta x_1}(T_E-T_P) + \frac{k\Delta A}{\Delta x_2}(T_W-T_P) \quad (135)$$

* Since the writing of this report the program has been extended to compute the Stanton numbers locally. The corresponding update to the program is given in Appendix E.

where ΔA = east face area of the cell at P

$$\Delta x_1 = x_E - x_P \tag{136}$$

$$\Delta x_2 = x_P - x_W \tag{137}$$

Also, the east-west finite-difference coefficients (i.e. A_E and A_W of equation (73)) for node P are set to zero.

(iii) Wall to wall radiation

The treatment of Ref 11 for radiant heat exchange between two long, gray, coaxial cylinders is followed.

Therefore, the enthalpy-equation source term at P is modified as:

$$Su_p = Su_p + Q_{rad} \tag{138}$$

where $$Q_{rad} = \frac{\sigma(T_{WP}^4 - T_P^4)}{\frac{1}{A_P e_1} + \frac{1}{A_{WP}}(\frac{1}{e_2} - 1)} \tag{139}$$

σ = Stefan-Boltzmann constant ;

$$A_P = r_{1,0}\Delta x; \tag{140}$$

$$A_{WP} = r_{2,i}\Delta x; \tag{141}$$

T_{WP} = temperature of duct wall at same x-location as P;

$r_{2,i}$ = inner radius of duct wall;

e_1 = emissivity of inner duct wall material;

e_2 = emissivity of outer duct wall material.

4.3.3 Heat transfer at the outer tube wall

The heat transfer effects at the duct wall are introduced by modifying the enthalpy source terms at the nodes WP and WS (Fig. 9). The nodes WW, WP, and WE actually lie on the inner surface of the duct wall (these are the nodes corresponding to i=NY, Fig. 2); however, for the purpose of heat transfer calculations, the enthalpy and temperature associated with these nodes are

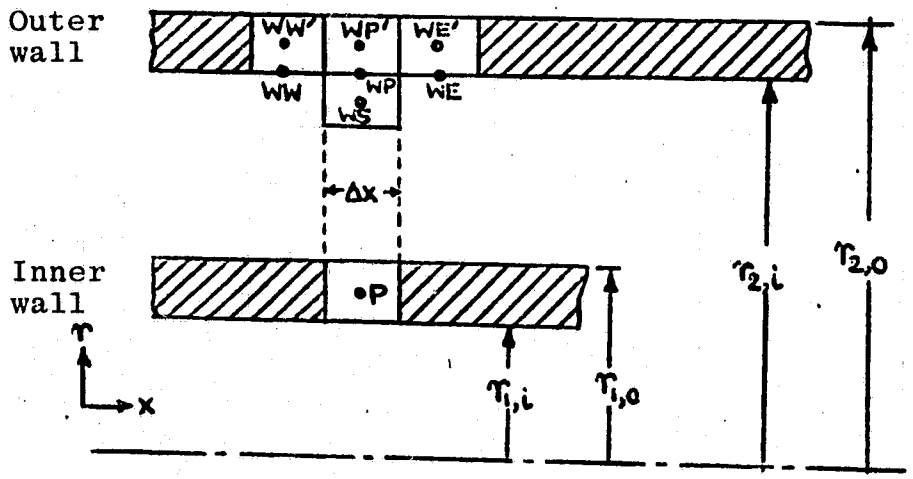


Fig. 9: Heat transfer calculation at the outer duct wall.

assumed to be the values at the middle of the duct wall (i.e. WE', WP', WW'). Also the TDMA solution for the enthalpy equation is extended to include WE', WP', WW' as internal nodes.

The various modes of heat transfer are summarised below:

(i) Heat transfer between wall and gases in the duct:

The method of treating this is identical to that discussed in Sec. 4.3.2(i) above. Again, the Stanton number is assumed to be 0.003.

(ii) Axial wall conduction

The method of treating axial wall conduction is identical to that discussed in Sec.4.3.2(ii) above.

(iii)Wall to wall radiation

This has also been discussed in Sec 4.3.2(iii) above. Its inclusion involves modifying the enthalpy source term at WP' as:

$$Su_{WP'} = Su_{WP'} - Q_{rad} \qquad (142)$$

where Q_{rad} is given by equation (139).

(iv) Free and forced convection from outer wall to surroundings

Since the flow is assumed to be axisymmetric, to consider free convection, the axis of the duct must be vertical; to consider forced convection, the axis of the duct must be parallel to the external free stream in which the duct is placed.

A brief study of the literature (e.g. Refs.11,12) shows that no simple correlations for calculating the free and forced convection for the above conditions exist. Most of the cases dealt with in

these references are for a cylinder with its axis normal to the free stream.

Therefore, in order to calculate the free and forced convection a prescribed Stanton number is assumed; again a value of 0.003 is assumed for lack of more accurate information. The inclusion of free and forced convection involves a modification of the enthalpy source at WP as:

$$Su_{WP} = Su_{WP} + St_{2,0}\ \rho|u_\infty|C_p\ (T_{surr} - T_{WP}) \qquad (143)$$

where u_∞ = the free stream velocity to which the duct is subjected;

T_{surr} = surroundings temperature.

(v) Radiation from outer wall to surroundings

This is included by modifying the enthalpy source term at WP as:

$$Su_{WP} = Su_{WP} + \sigma e\ (T_{surr}^4 - T_{WP}^4).\ \Delta x.\ r_{2,0} \qquad (144)$$

4.3.4 Heat transfer at the end wall

The end wall AB (Fig. 10) is treated similarly to the outer cylindrical wall AC. The TDMA solution is extended (for the enthalpy equation) to include the nodes in the wall AB. The only difference in the treatment of the wall AB (from the wall AC) is in the wall to wall radiation calculation; this does not exist since the wall AB is assumed not to exchange radiant energy with the other walls. This is consistent with the assumption made so far that the radiation leaving a wall is perpendicular to it. Instead the radiation to the surroundings will be from both surfaces of this wall and so has double the value given by the equation similar to (144).

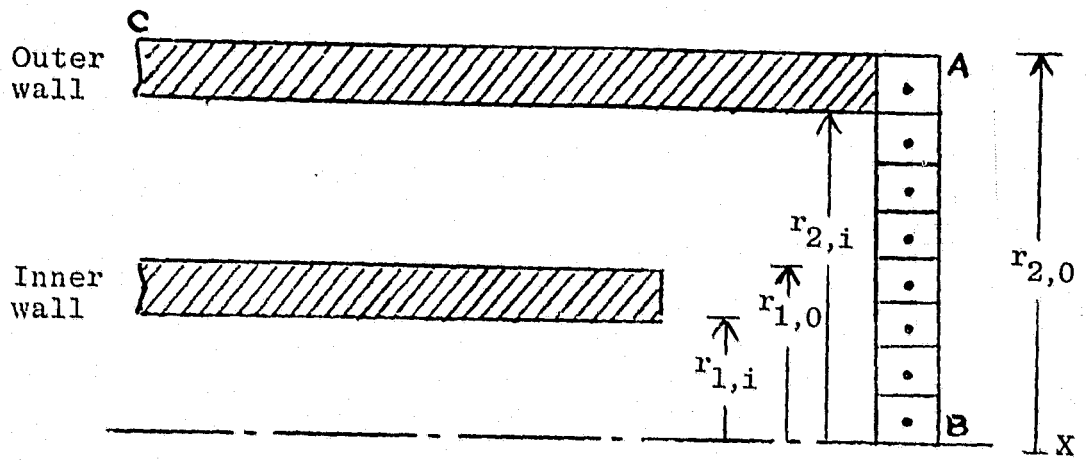


Fig. 10: Heat transfer calculation at end wall.

5. THERMODYNAMIC AND ELEMENT DATA

5.1 Element Data

The following information is required to describe the set of elements which make up the chemical species present in the system:

- the element symbol (e.g. C, O, H, and N);
- the corresponding atomic weight.

5.2 Thermodynamic Data

The thermodynamic data for constant pressure specific heat, enthalpy, and the entropy at one atmosphere for the chemical species are the same as those used in Ref. 2. These properties are expressed as polynomials in temperature.

$$\frac{C_p}{R} = Z_1 + Z_2T + Z_3T^2 + Z_4T^3 + Z_5T^4 \qquad (145)$$

$$\frac{h}{RT} = Z_1 + \frac{Z_2T}{2} + \frac{Z_3T^2}{3} + \frac{Z_4T^3}{4} + \frac{Z_5T^4}{5} + \frac{Z_6}{T} \qquad (146)$$

$$\frac{s^o}{R} = Z_1 \log T + Z_2T + \frac{Z_3T^2}{2} + \frac{Z_4T^3}{3} + \frac{Z_5T^4}{4} + Z_7 \qquad (147)$$

There are thus seven coefficients $Z_1 \ldots\ldots Z_7$ for each one of the chemical species for each one of two temperature ranges, 300°K to 1000°K, and 1000°K to 5000°K. The pressure effects on the thermodynamic data were not taken into account.
The enthalpy equation (146) includes both the sensible enthalpy and the standard-state enthalpy of formation. The entropy s^o includes the low-temperature enthalpy of formation as also the chemical and sensible contributions.
The entropy s at any arbitrary pressure is given by:

$$s = s^o - R\log (p/p_o) \qquad (148)$$

where p_o = standard atmospheric pressure.

6. KINETICS DATA

The following information is required to specify the chemical kinetics of the system considered:

- the set of elementary reactions making up the assumed chemical-kinetic mechanism:
- the Arrhenius constants for each elementary reaction.

In the present study, only reactions of the following types are considered:

$$A + B \rightarrow C + D \quad , \text{MODE=1} \tag{149}$$

$$AB + M \rightarrow A + B + M \quad , \text{MODE=2} \tag{150}$$

$$A + B + M \rightarrow AB + M \quad , \text{MODE=3} \tag{151}$$

The forward reaction rate constant is expressed as:

$$k_{f_j} = A_j T^{B_j} \exp(-T_{actj}/T), \text{ for reaction } j \tag{152}$$

The Arrhenius constants A_j, B_j and T_{actj} are supplied for each one of the reactions considered.

The reverse reaction rate constant may either be directly specified as above, or it may be calculated from a knowledge of the forward rate constant and the equilibrium constant:

$$k_{bj} = \frac{k_{fj}}{K_{cj}} \tag{153}$$

7. RESULTS AND DISCUSSIONS

7.1 Introduction

In this chapter results are presented for two test cases: one without chemical reaction (cold flow) and one with chemical reaction. Before presenting the results certain computational details are given in the next section.

7.2 Computational details

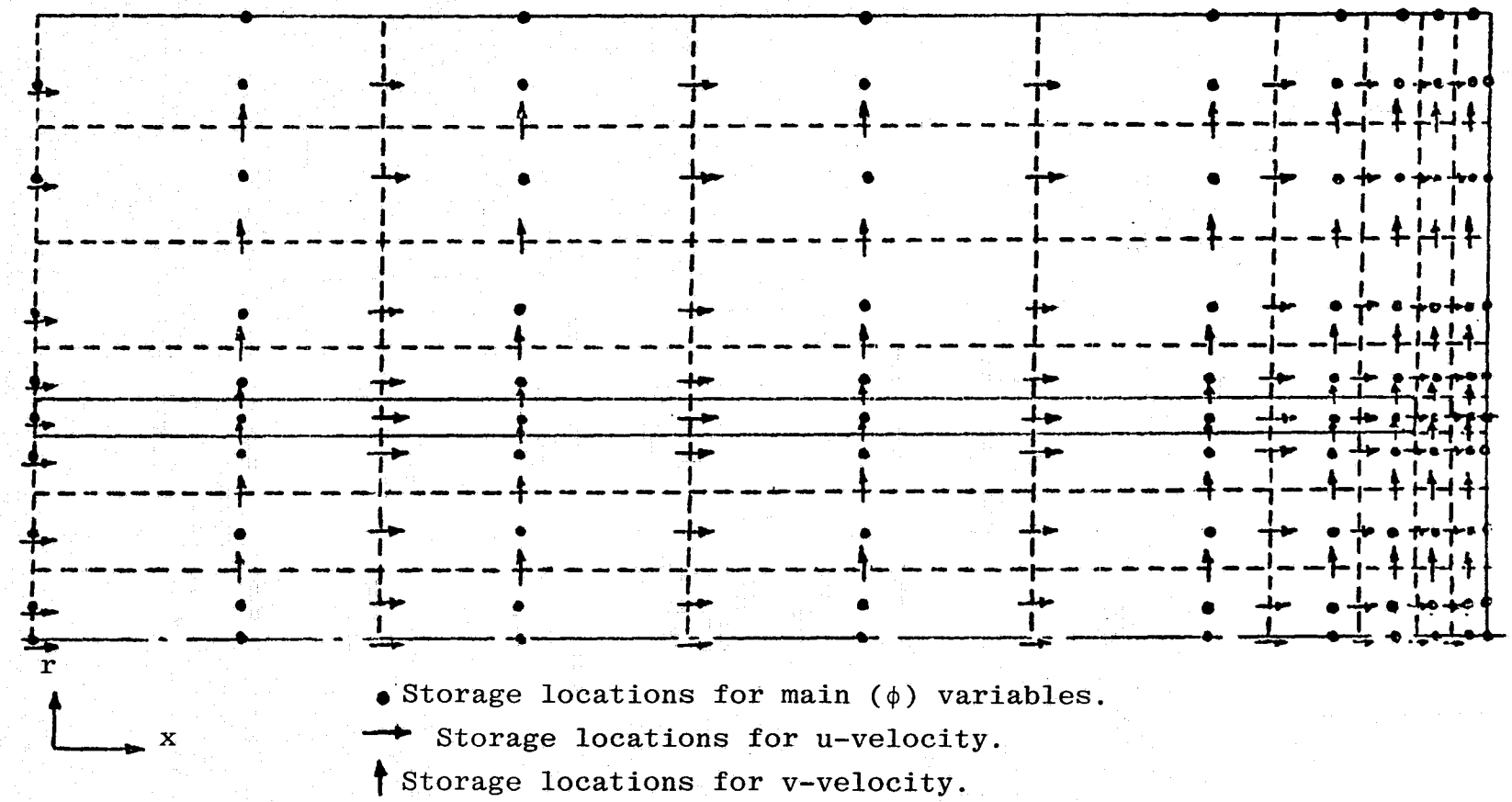
(i) Variables computed

At each grid node, 22 variables were computed for the test case with chemical reaction. The variables obtained from the solution of partial differential equations were: the axial and radial velocity components u and v, the pressure p, the stagnation enthalpy $\tilde{h}$, the mixture fraction f, the mass fraction of unburnt fuel m_{fu}, and the mass fractions of the species N, NO, NO_2, and N_2O. The variables obtained through the use of auxiliary algebraic equations were: the mass fractions of the species CO, CO_2, H, H_2, H_2O, N_2, O, OH, and O_2, density, effective viscosity and temperature.

For the test case without chemical reaction, the variables u, v and p were obtained from the solution of partial differential equations, and the effective viscosity from an auxiliary algebraic equation.

(ii) Grid used:

The grid used in both the test cases had 10 nodes in the axial and in the radial directions. The distribution of the nodes was non-uniform in both the directions and is illustrated in Fig. 11.



Scale: 1:1 axial, 10:1 radial.

Fig. 11: Grid distribution for test cases.

(iii) Convergence:

The convergence criteria adopted were:

- The normalised residual errors of each of the variables u, v, $\tilde{h}$, f and m_{fu} which were solved by a line-by-line procedure, should be less than 0.5%.
- The mass fractions of N, NO, NO_2, and N_2O which were obtained by a point-by-point solution procedure should remain within 0.1% of their values from one iteration to the next.

(iv) Physical and chemical data:

The thermochemical data for all the species were obtained from Ref. 2. Reaction rate data are given in Table 2.

(v) Geometrical and other data:

The parameters defining the two test cases are given in Table 3.

7.3 Results of Test Case 1

The problem specification for test case 1 is given in Table 3. This case in which chemical reaction is not considered is not of much practical interest and the aim in performing it was mainly to test the hydrodynamic features of the computer code.

Figure 12 shows the axial velocity profile at various cross-sections of the combustor. The behaviour is as expected. On entry into the duct, the fuel and air jets exhibit mixing and towards the end of the inner duct the flow shows signs of approaching developed pipe flow. Radial momentum effects are of some importance at the entrance of the duct, but for the bulk of the flow in the inner duct, radial momentum effects are

Table 2. Reaction rate data (in S.I. Units)

No.	Reaction	A	B	T_{act}	Ref.
1	$N+NO \rightleftarrows N_2+O$	1.500E10	0	0	3
2	$N+O_2 \rightleftarrows NO+O$	5.998E6	1.0	3.172E3	3
3	$OH+N \rightleftarrows H+NO$	5.998E8	0.5	4.028E3	3
4	$H+N_2O \rightleftarrows OH+N_2$	7.998E10	0	7.553E3	3
5	$N_2O+O \rightleftarrows NO+NO$	1.000E11	0	1.500E4	3
6	$N_2O+M \rightleftarrows N_2+O+M$	1.000E11	0	2.518E4	3
7	$N+O+M \rightleftarrows NO+M$	6.397E10	-0.5	0	6
8	$NO_2+O \rightleftarrows NO+O_2$	1.000E10	0	3.000E2	6
9	$NO_2+M \rightleftarrows O+NO+M$	1.099E13	0	3.300E4	6

Forward rate constant $k_f = AT^B \exp(-T_{act}/T)$

Reverse rate constant obtained from forward rate and equilibrium constants.

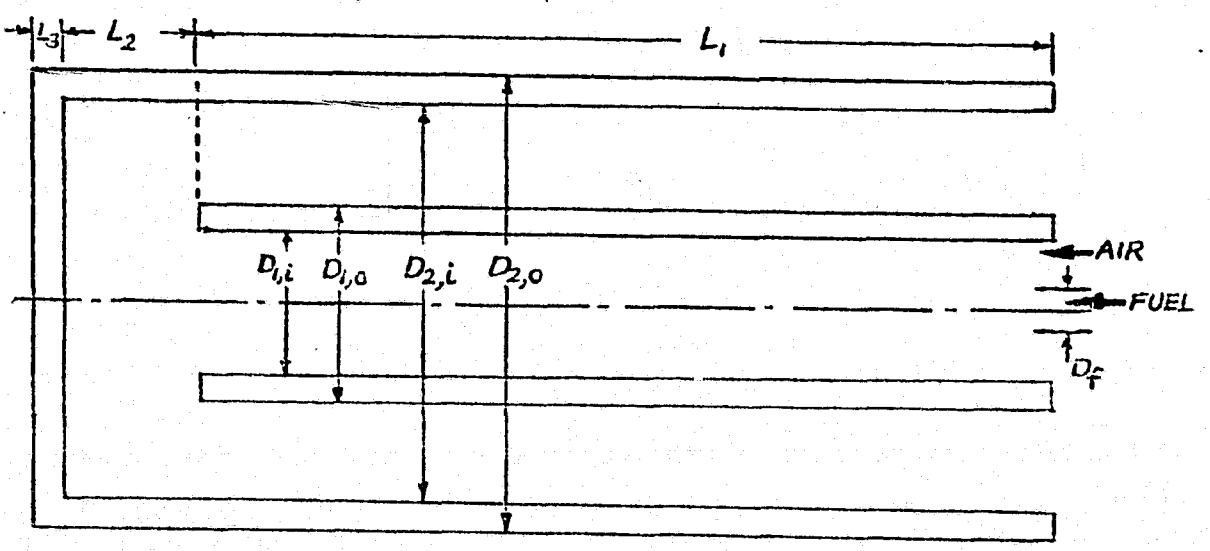
Hydrocarbon oxidation reaction rate = $0.01\ m_{fu}^{m_{ox}} \exp(-18000/T)$

Table 3: Specification of Test Cases

$T_{ao} = T_{fo} = 275^{o}K$	$m_{ao} = 3.6 \times 10^{-4}$ kg/s
P_o = 2 atmospheres	$m_{fo} = 1.4 \times 10^{-5}$ kg/s: (ϕ=.66)
L_1 = 20 cm	$D_{1,o}$ = 0.7 cm
L_2 = 1 cm	$D_{2,i}$ = 1.8 cm
D_f = 0.1 cm	$D_{2,o}$ = 2.1 cm
$D_{1,i}$ = 0.6 cm	

Heat transfer data (for case 2 only)

All Stanton numbers (see Sec. 4.3) = 0.003.
Conductivity of wall material = 41.84 Joules/m.sec.^{o}K.
Emissivity of all walls = 0.05.
Surroundings: temperature = 300^{o}K;
velocity = 1 m/sec.



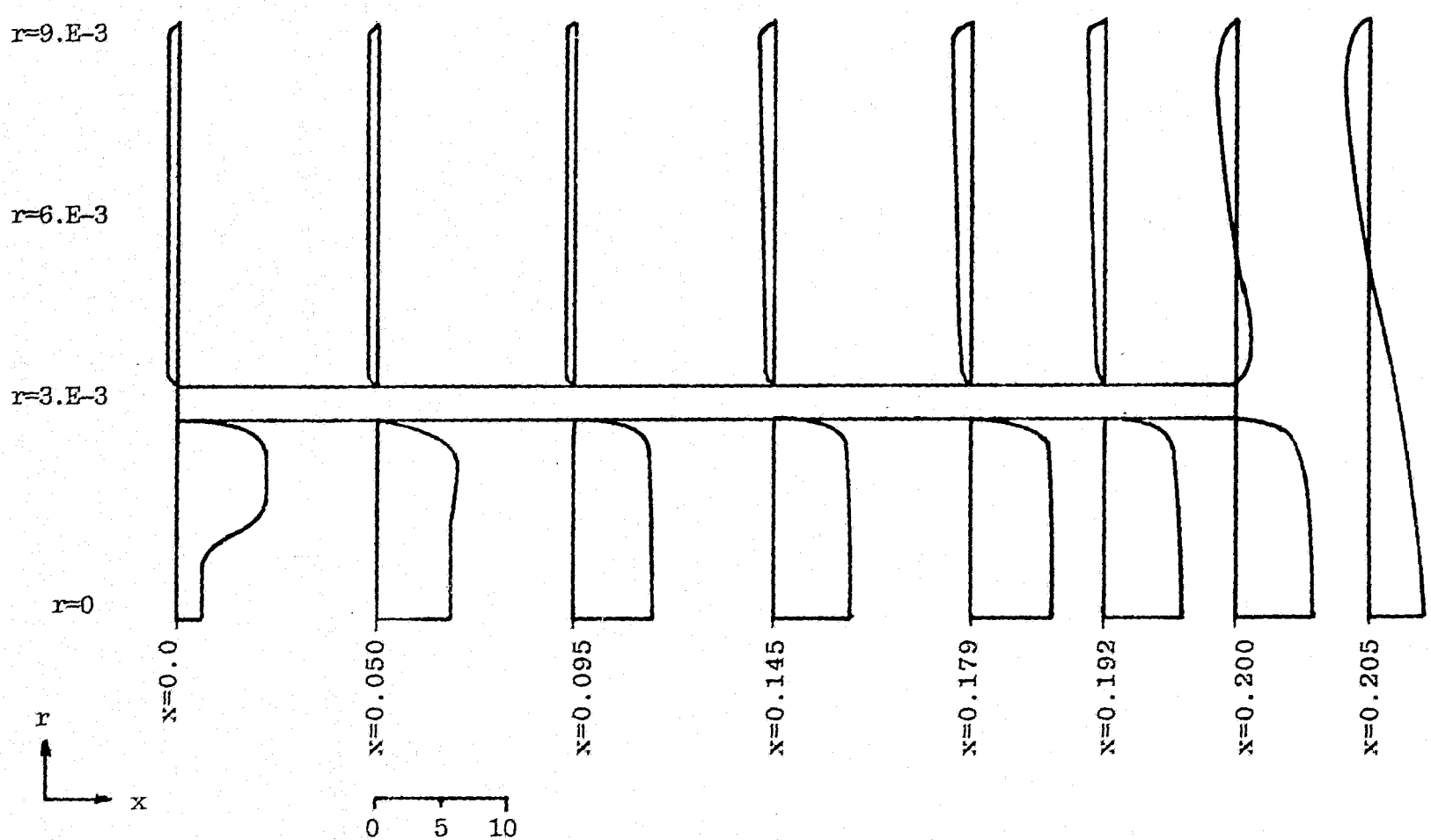


Fig. 12: Profiles of u-velocity (m/sec); Test case 1

negligible; and the pressure field is essentially uniform in the radial direction. This permits the calculation scheme to be simplified by: cutting out the solution of the radial momentum equation, assuming the pressure to be a function of axial distance alone and obtaining the radial velocity directly from the continuity equation. In the present work, however, this simplification has not been introduced, since the aim was to develop a general program which could handle different geometries in which radial momentum transfer might be significant all through the flow field.

At the end of the inner duct, flow reversal into the outer duct occurs and the pressure at the end wall rises as in stagnation flow. In the outer duct, again towards the end the flow exhibits similar characteristics as at the end of the inner duct: i.e. pressure radially uniform and radial velocities small compared to the axial velocities.

7.4 Results of Test Case 2

The problem specification for test case 2 is given in Table 3. This is the case of greater practical interest and it demonstrates all the features of the computer program.

Figure 13 shows the axial velocity profile at various cross-sections of the combustor. The behaviour is qualitatively similar to that of test case 1. Quantitatively, the velocities are slightly higher in the inner duct (as compared to test case 1); this is due to the reduced density brought about by the preheating of the incoming gases. In the outer passage, the velocities undergo a rapid increase through the flame zone as the density drops rapidly. Comments about radial momentum effects made in Section 7.3 apply to this test case also.

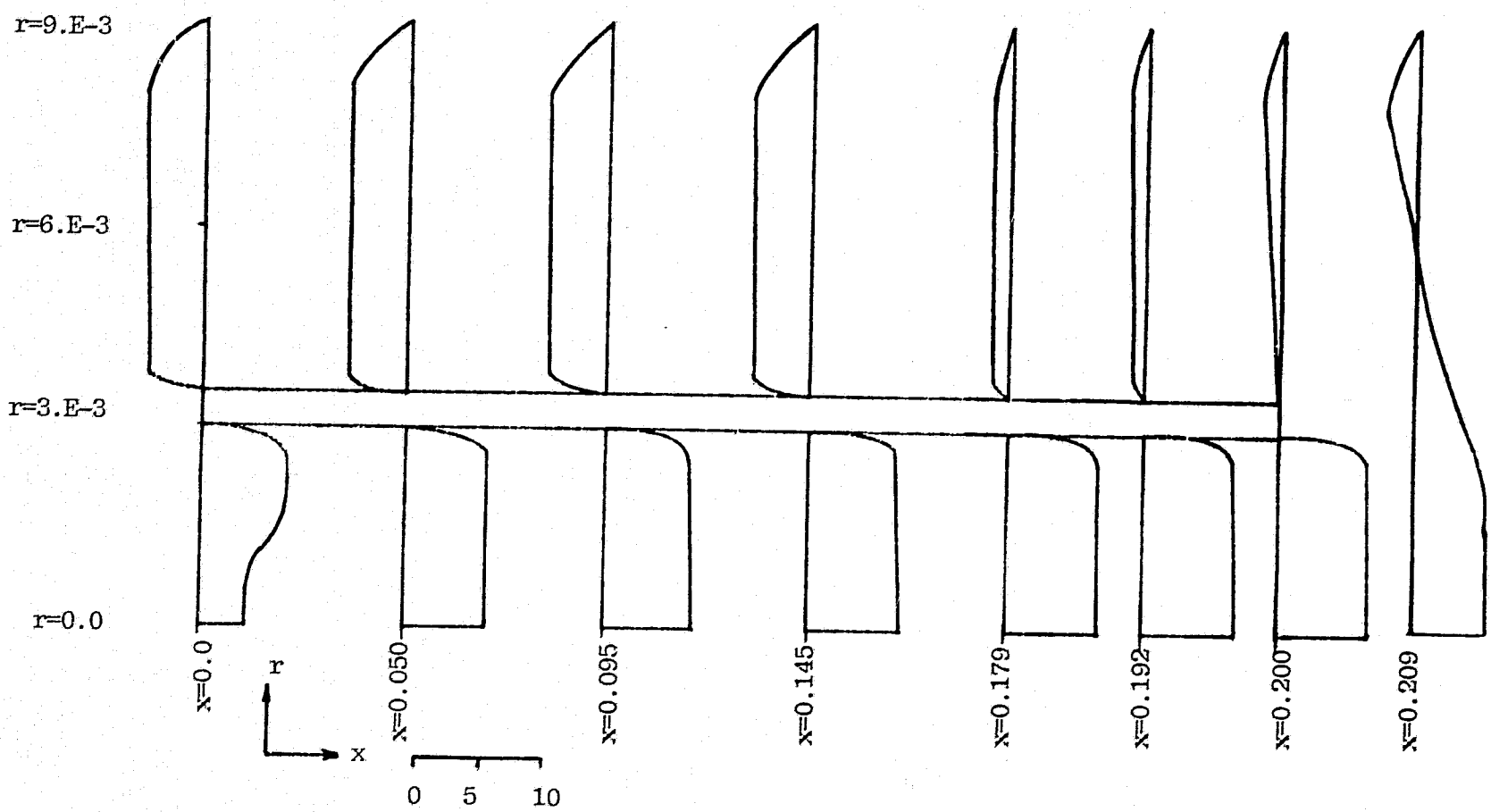


Fig. 13: Profiles of u-velocity (m/sec); Test case 2

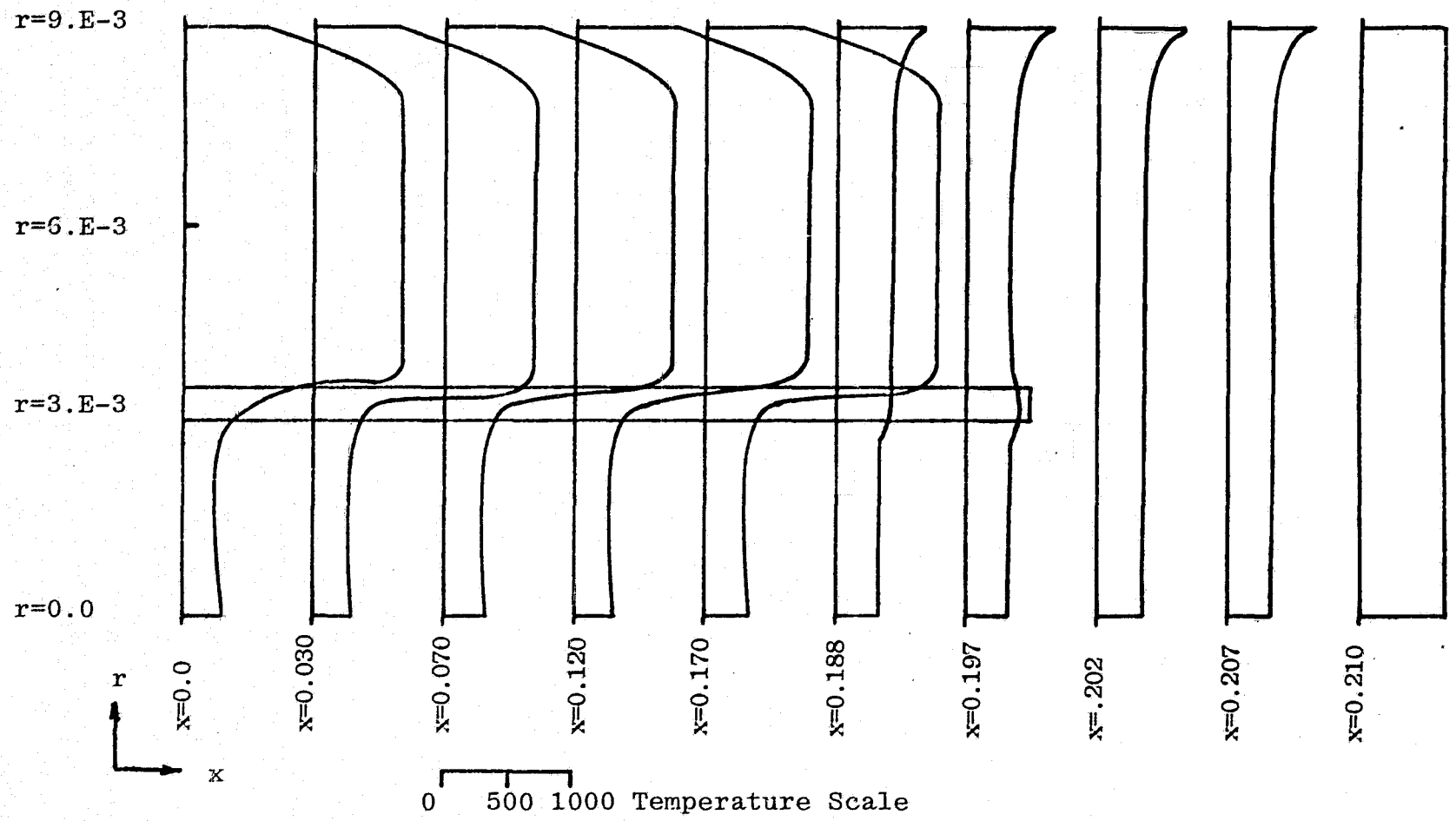


Fig.14: Profiles of temperature (degrees K)

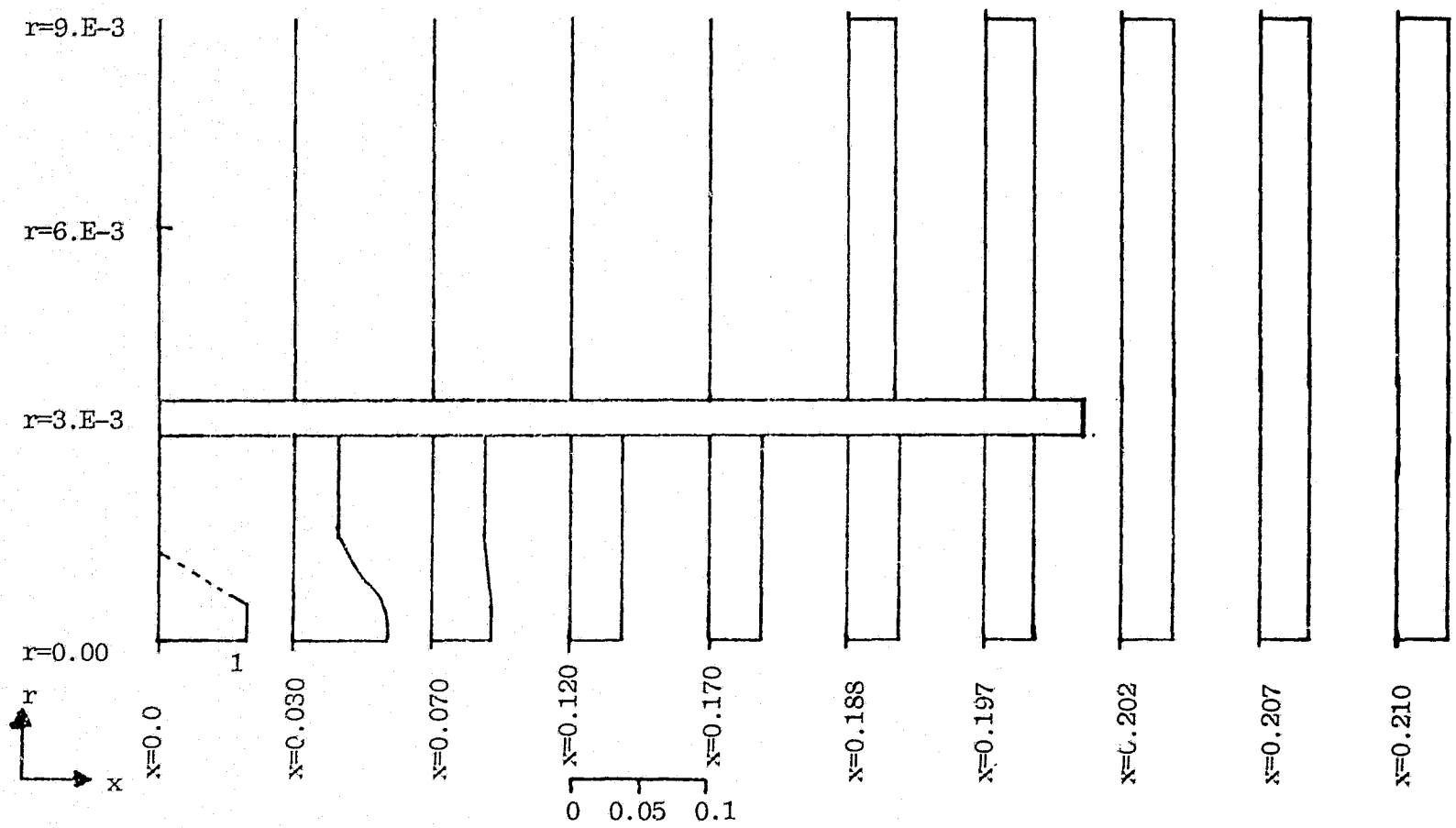


Fig. 15: Profiles of Fuel mass fraction

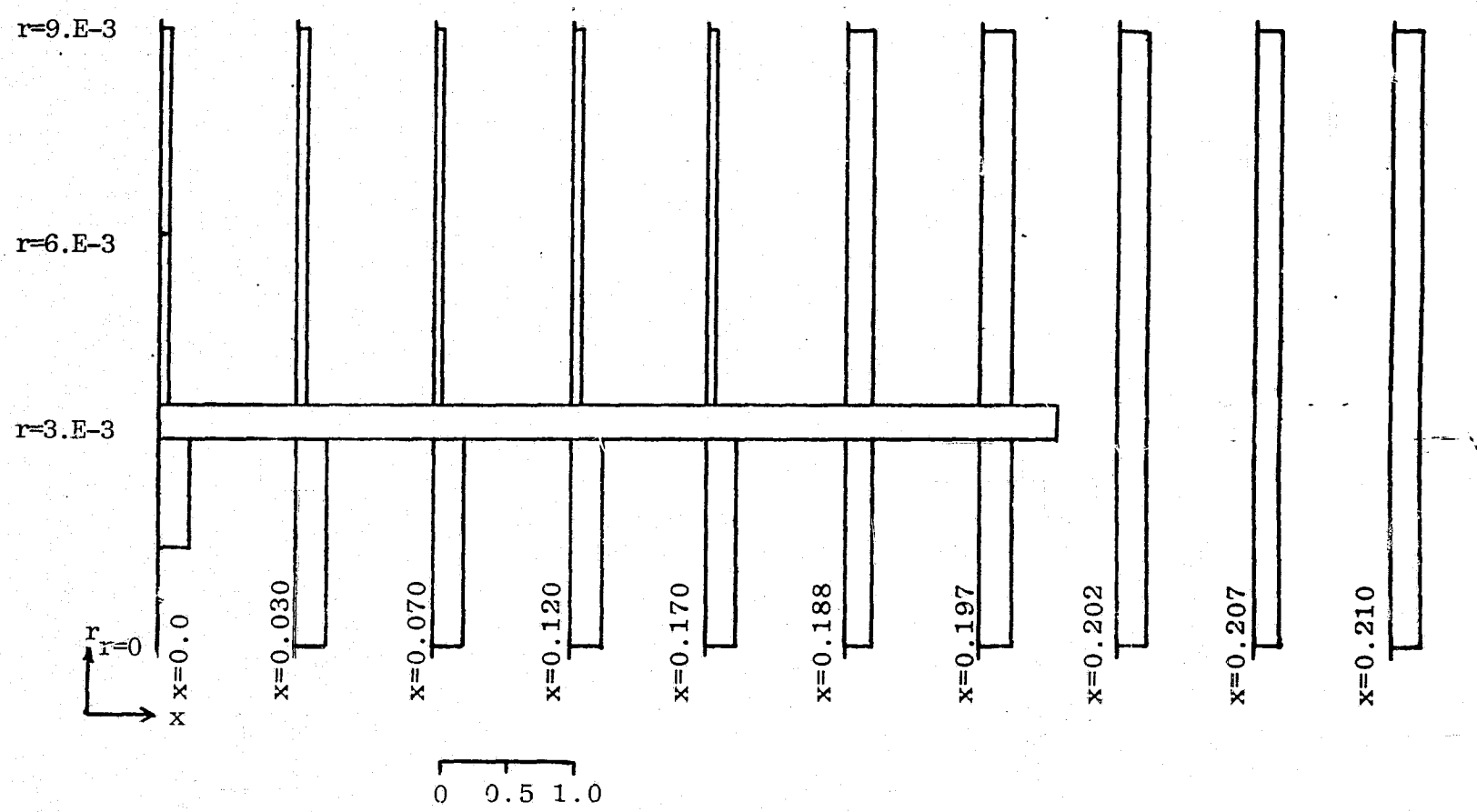


Fig. 16: Profiles of oxygen mass fraction

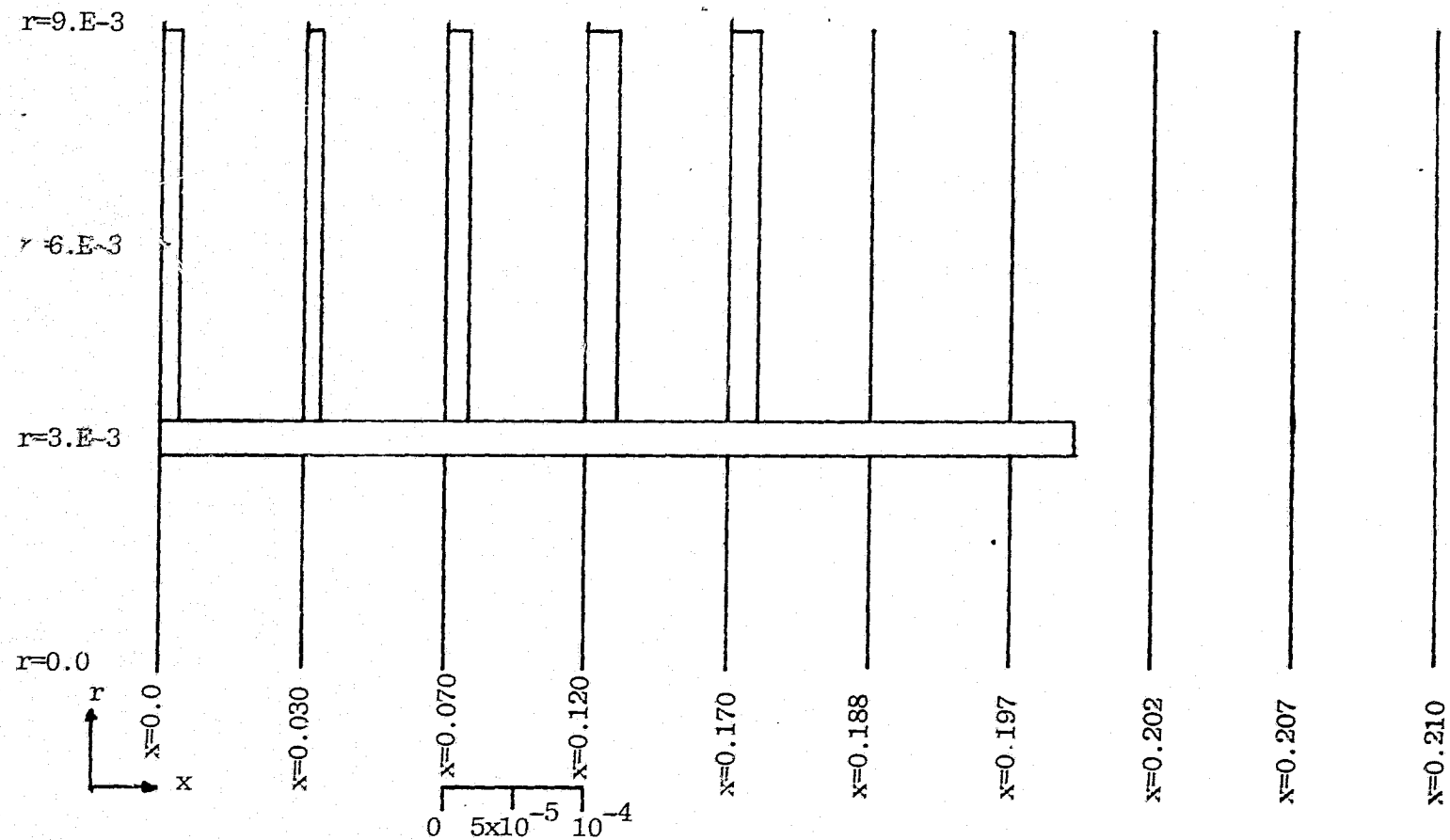


Fig. 17: Profiles of CO mass fraction

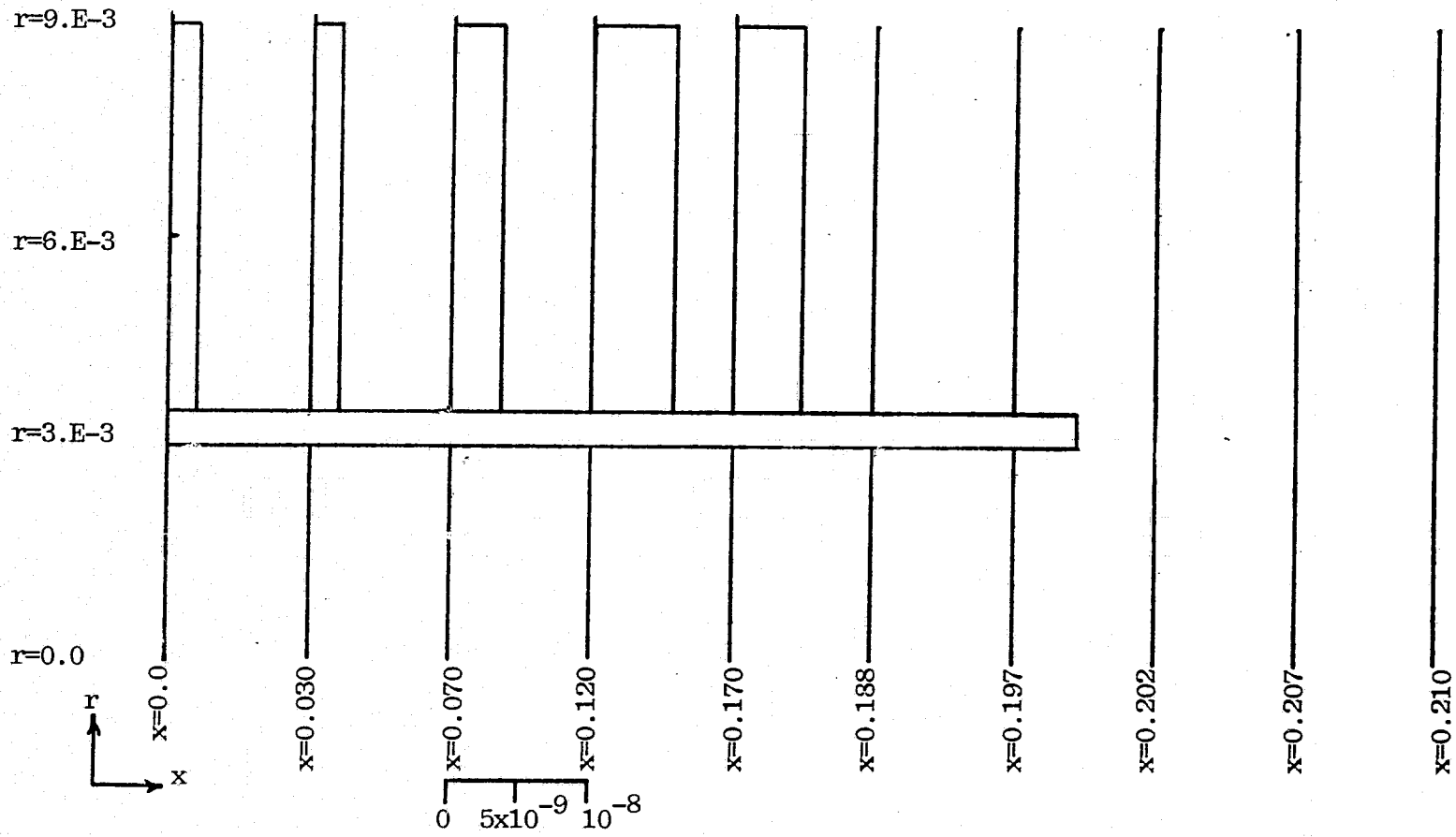


Fig. 18: Profiles of H mass fraction

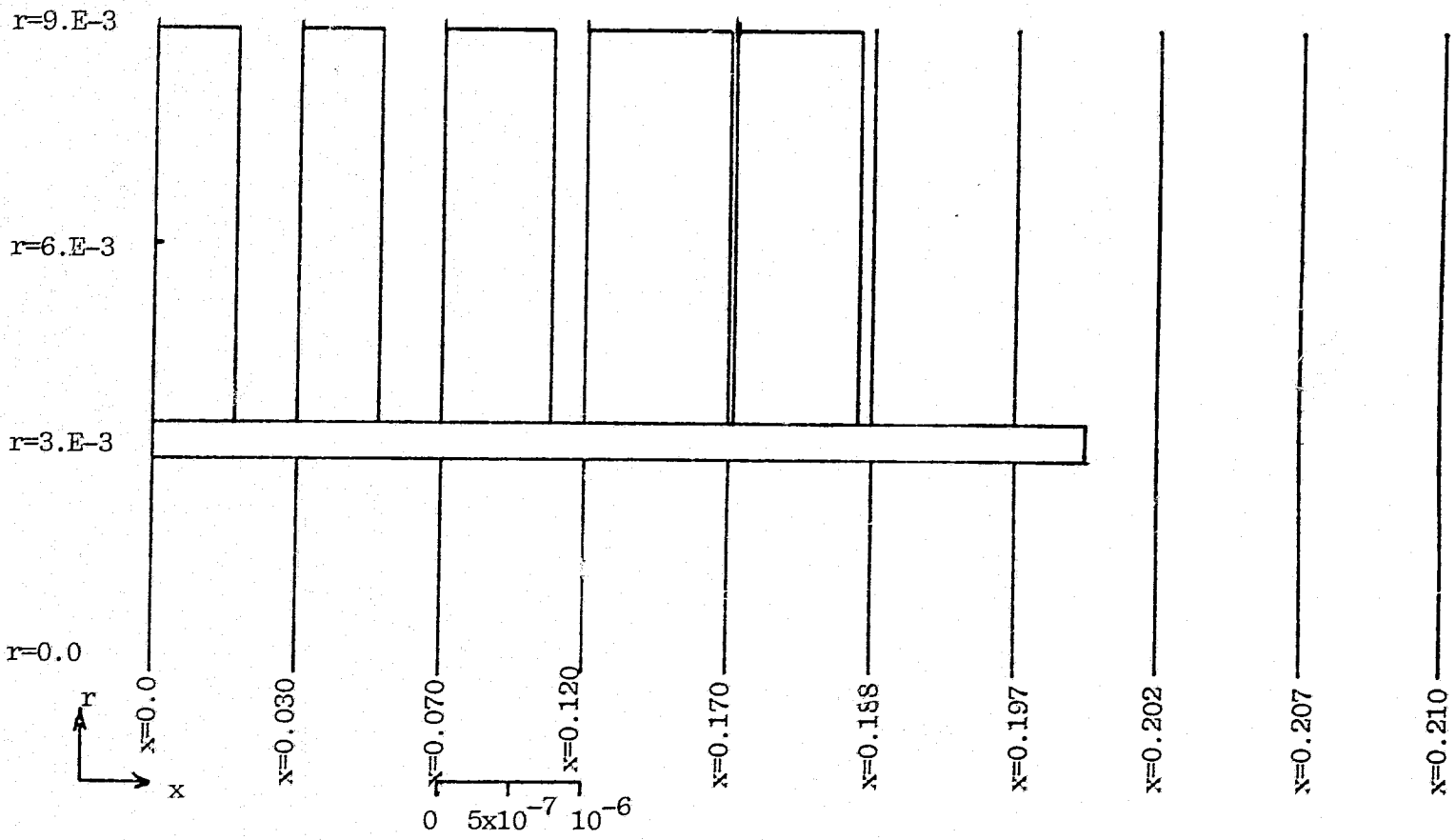


Fig. 19: Profiles of H_2 mass fraction

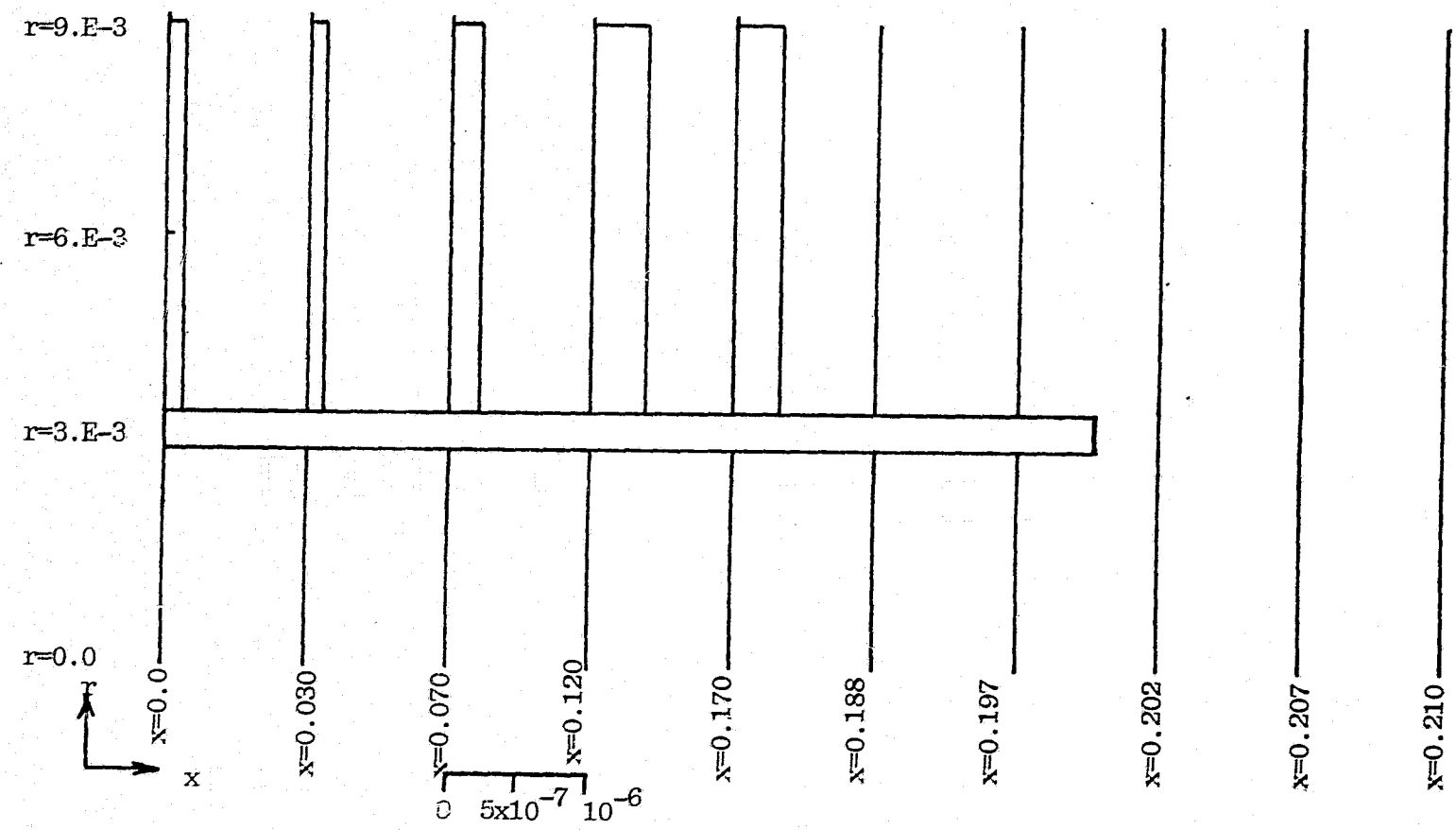


Fig. 20: Profiles of O mass fraction

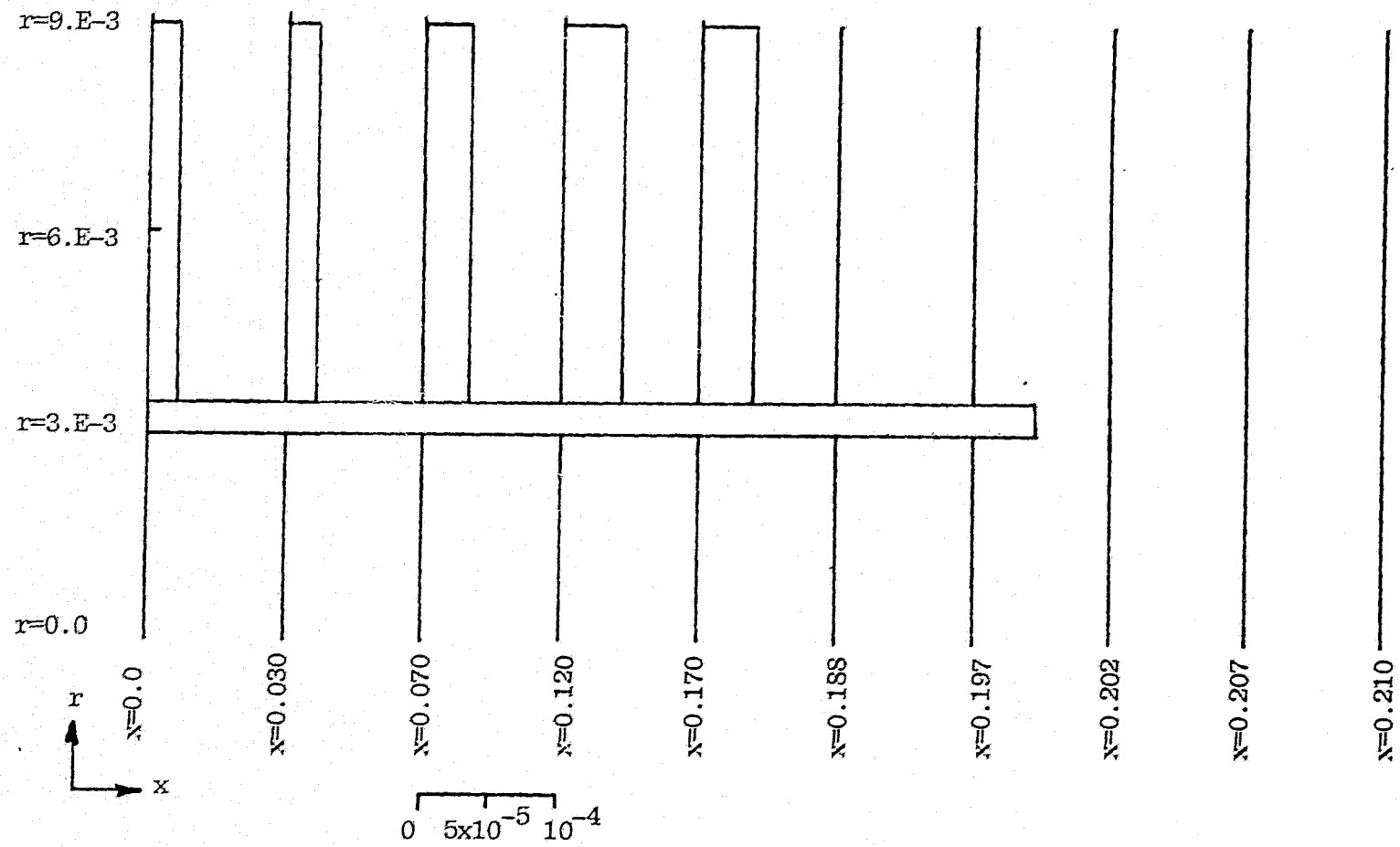


Fig. 21: Profiles of OH mass fraction

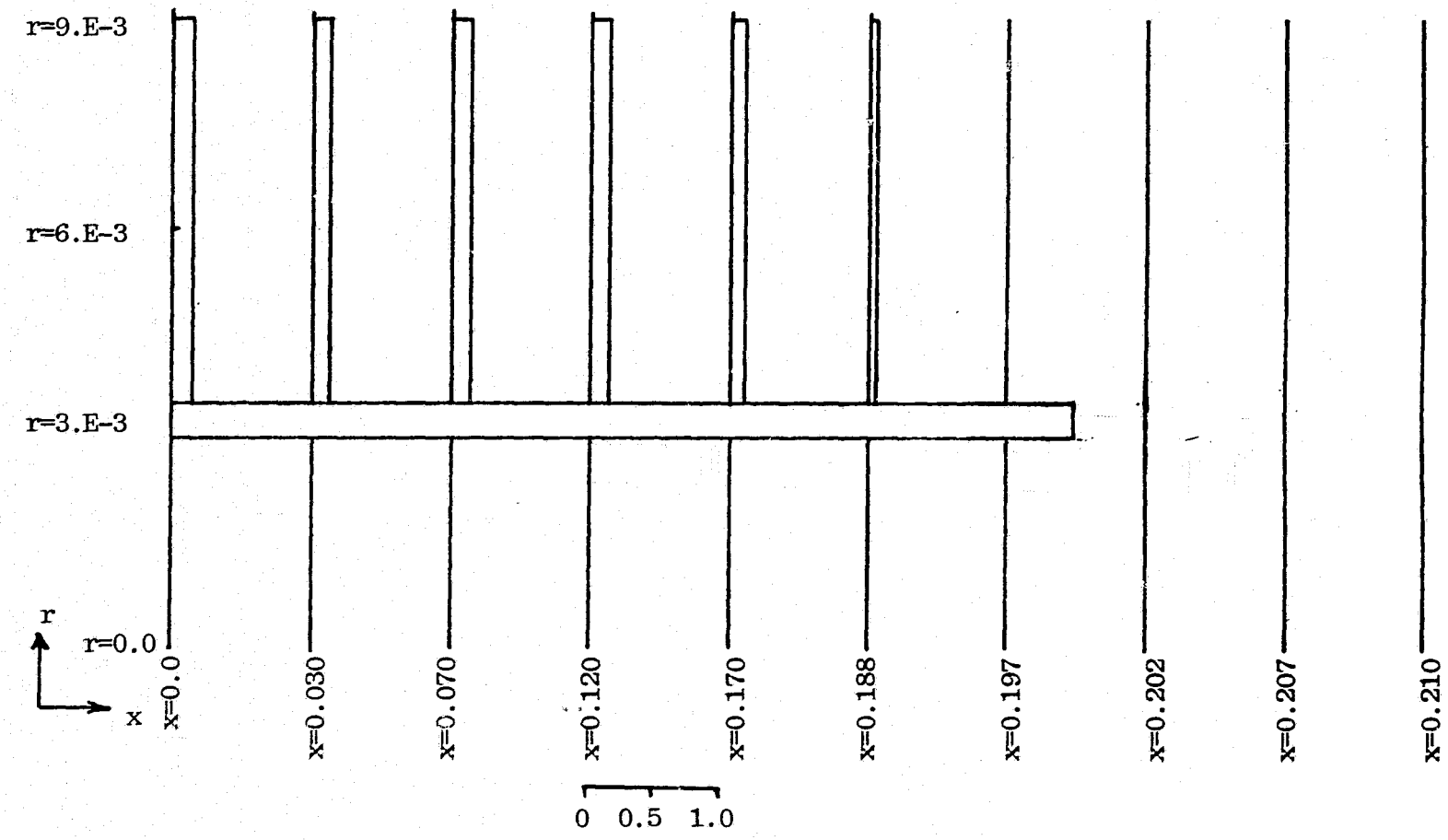


Fig. 22: Profiles of CO_2 mass fraction

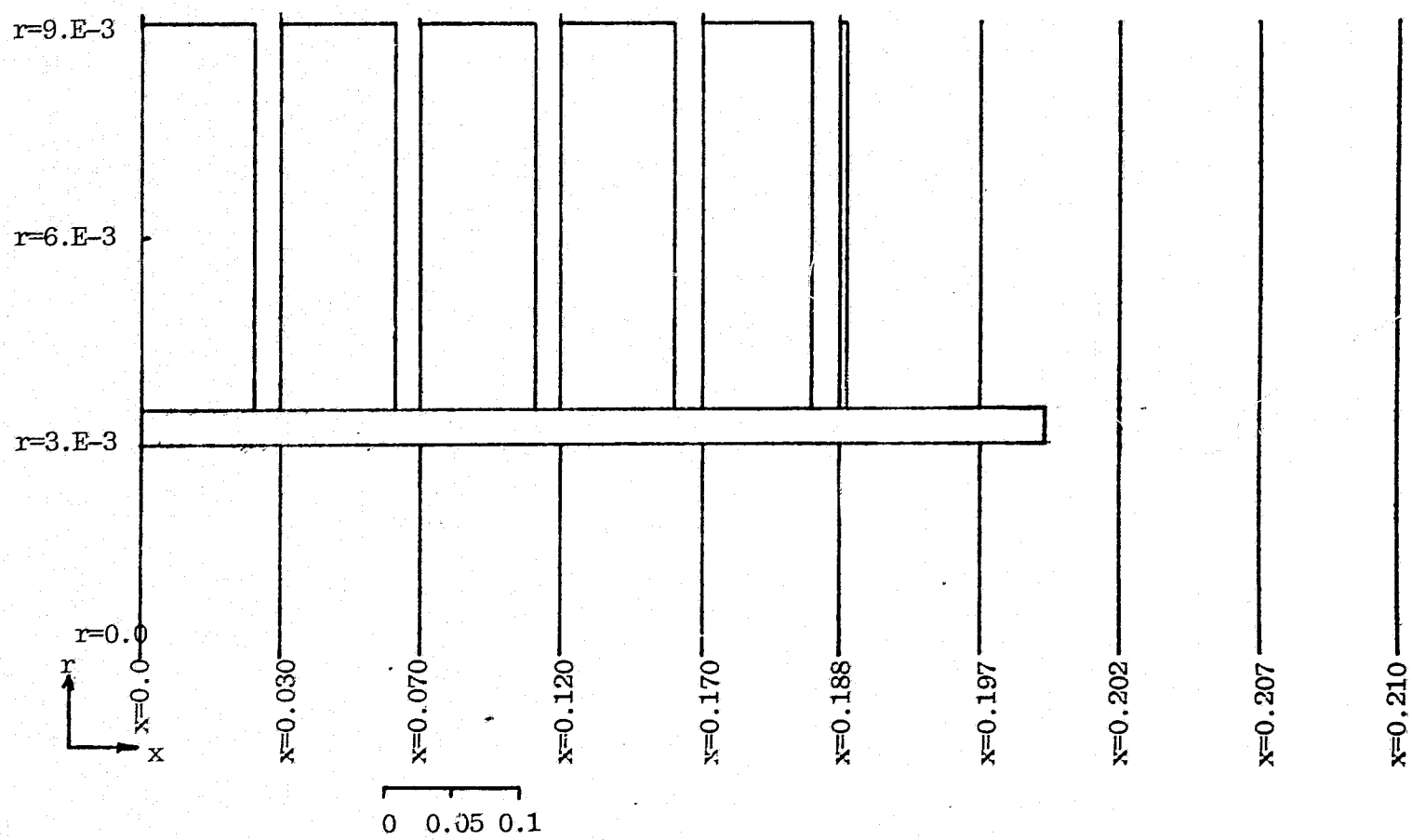


Fig. 23: Profiles of H_2O mass fraction

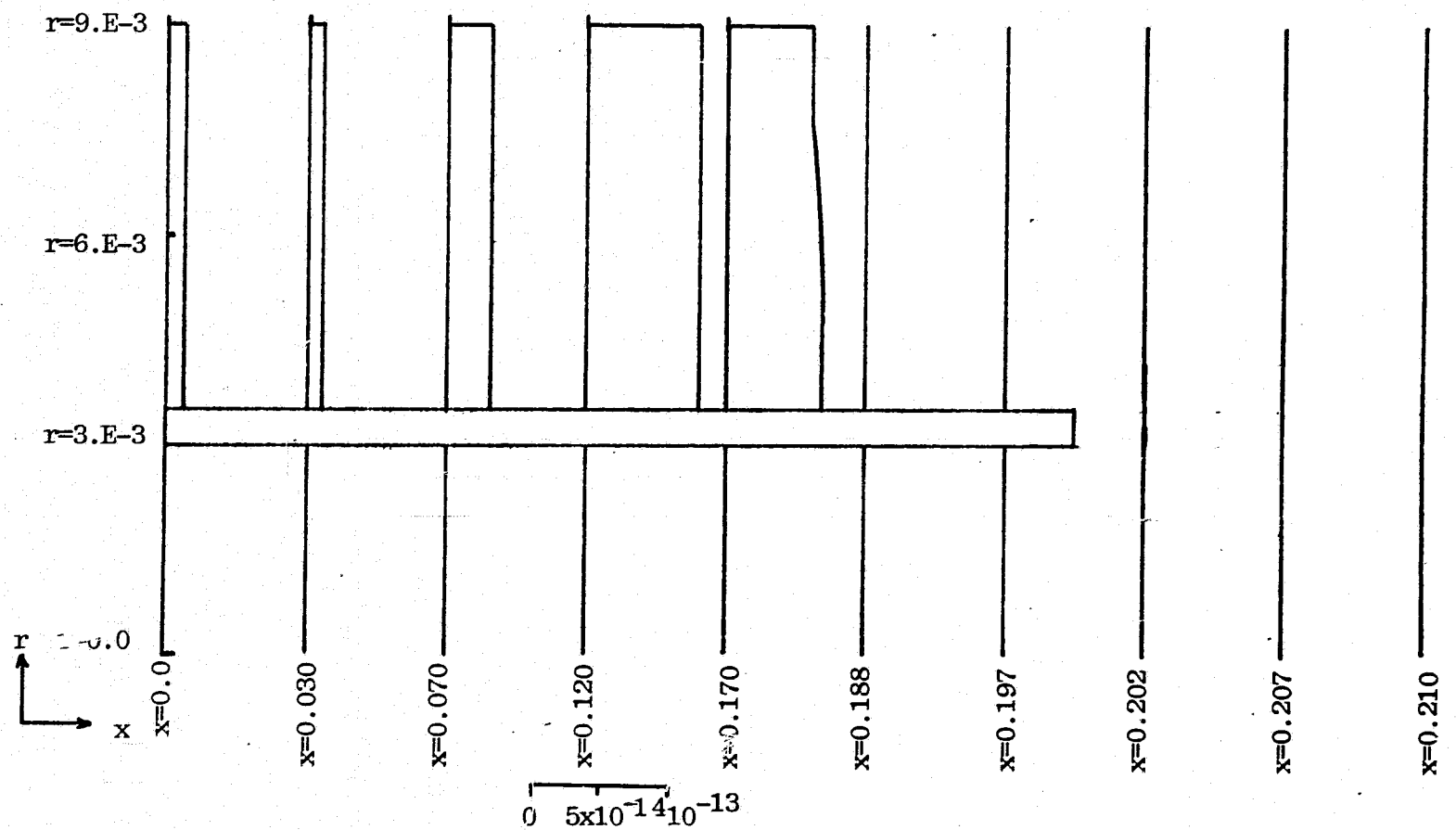


Fig. 24: Profiles of N mass fraction

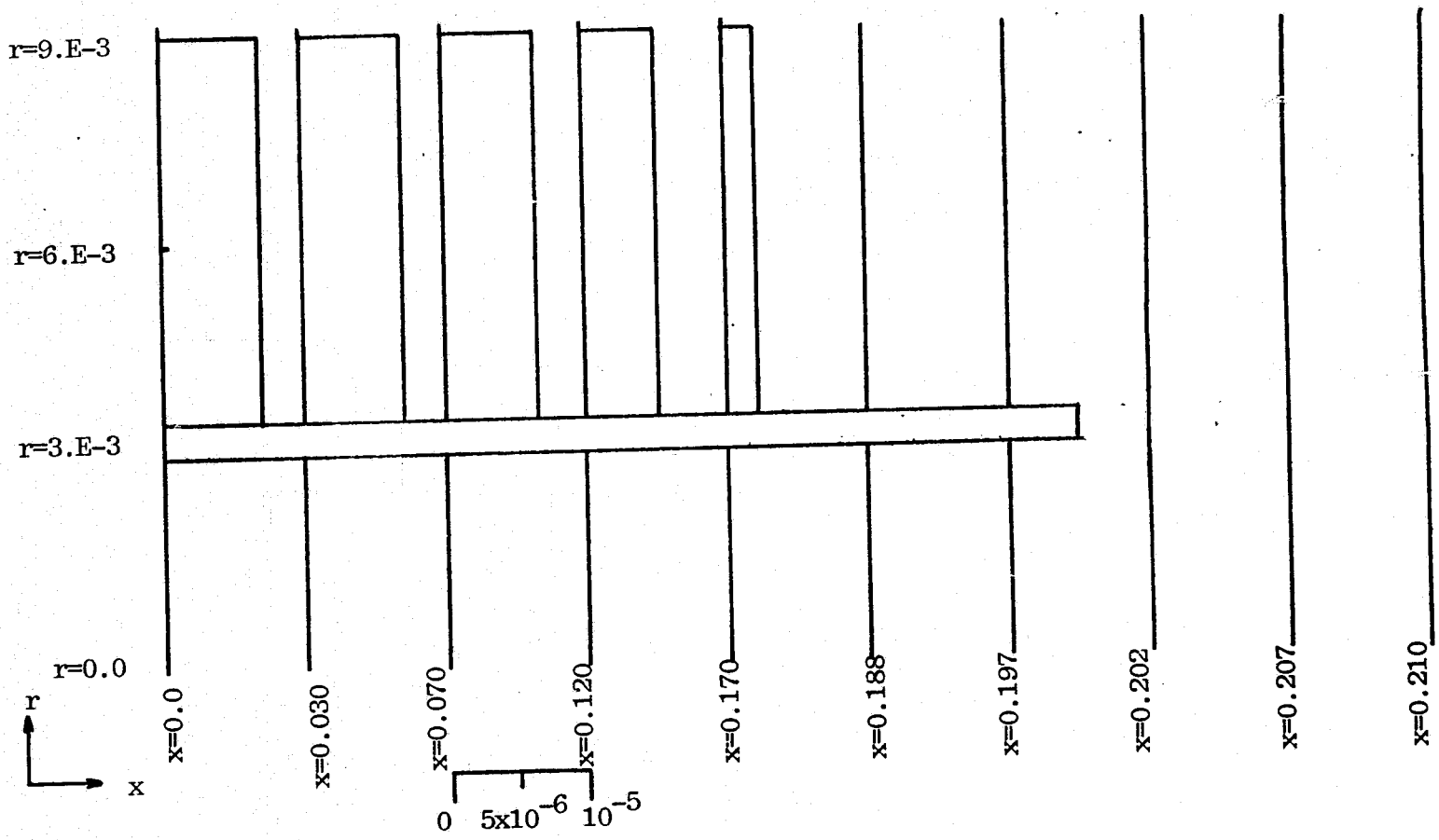


Fig. 25: Profiles of NO mass fraction

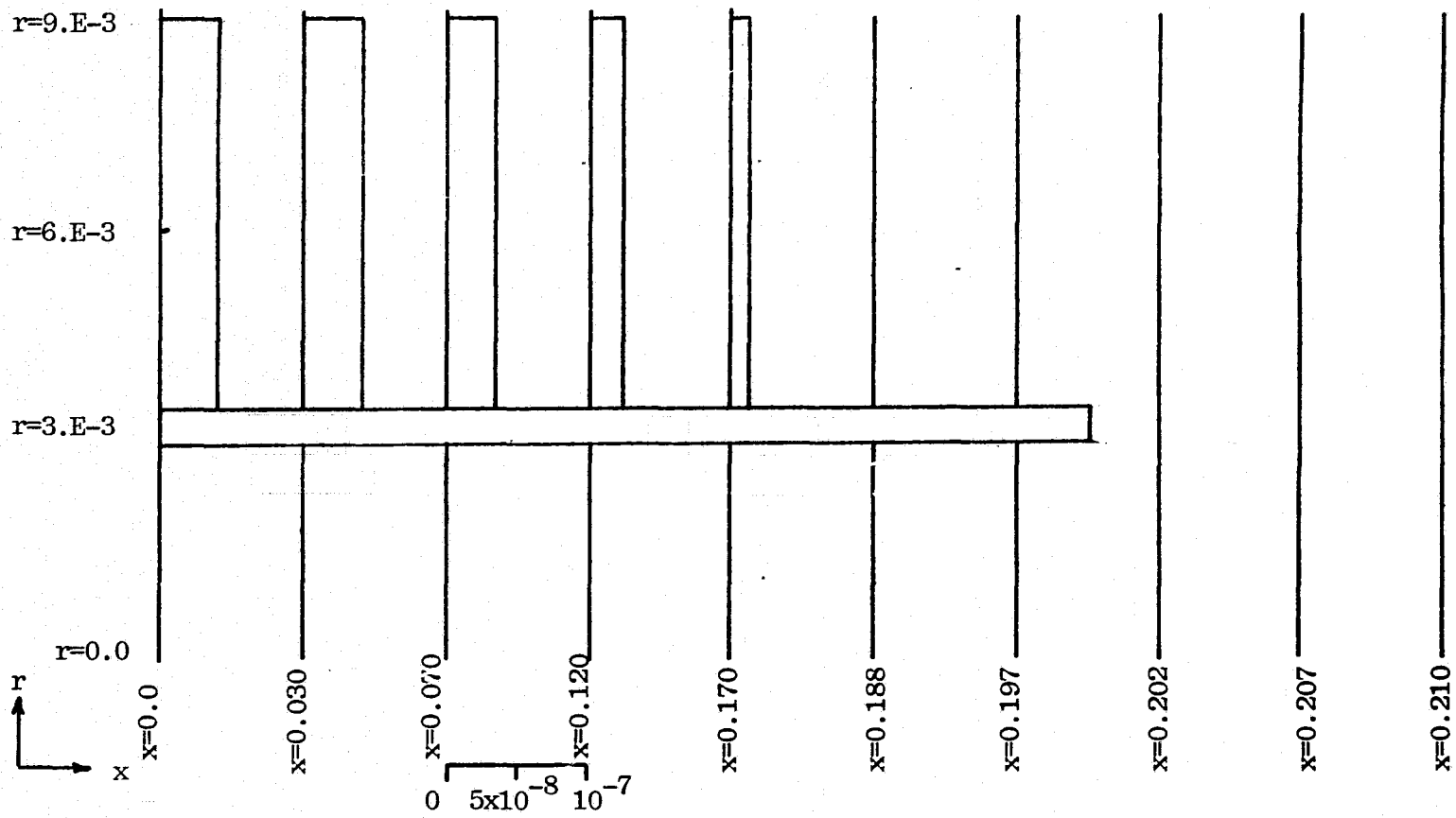


Fig. 26: Profiles of NO_2 mass fraction

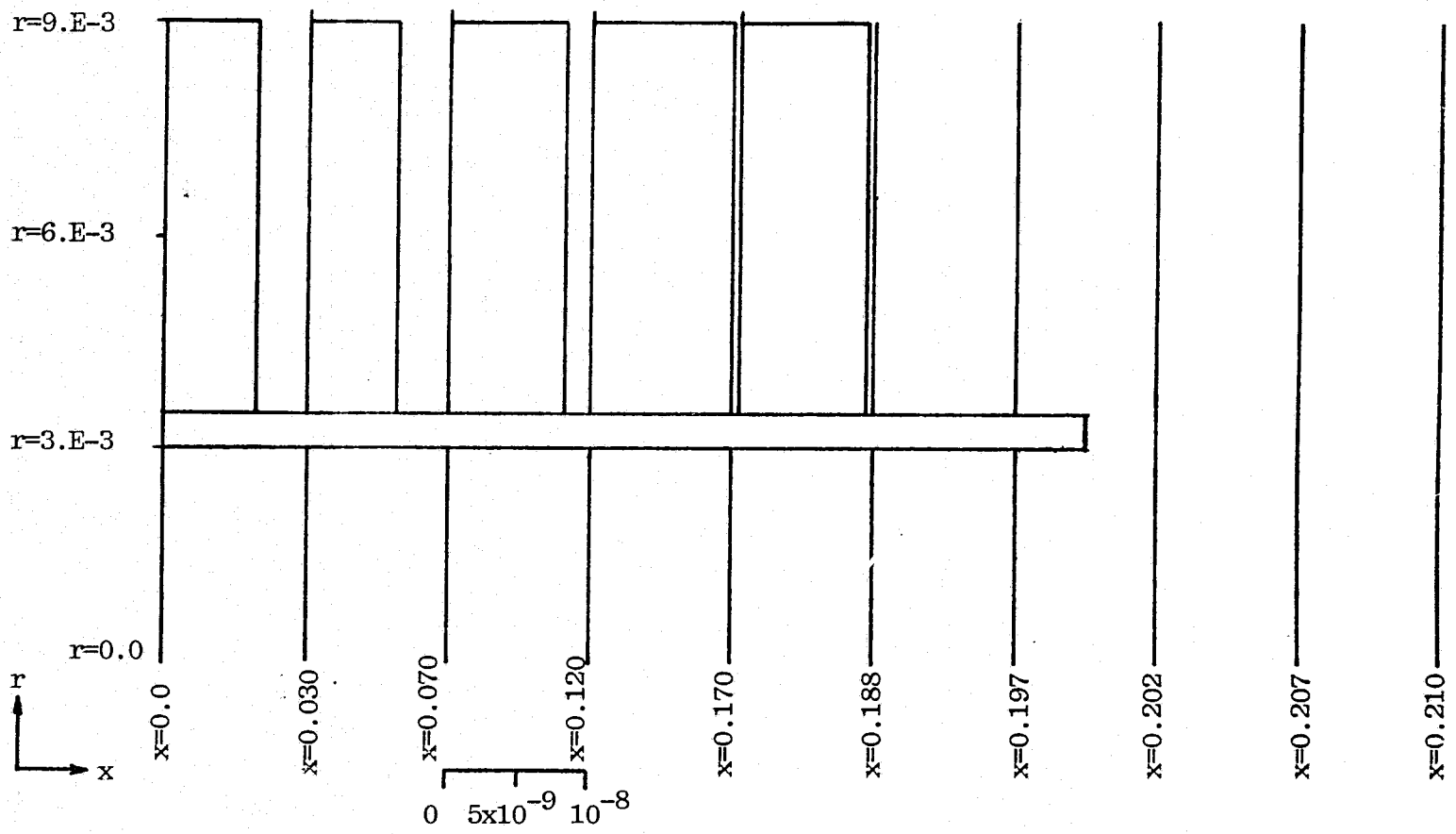


Fig. 27: Profiles of N_2O mass fraction

Figure 14 shows the temperature profile at various cross-sections of the combustor. The slight rise in temperature in the inner duct is due to the conduction of heat through the wall from the hot gases in the outer duct. After flow reversal into the outer duct, combustion occurs and the temperature rises rapidly. In the post-flame zone there is a slight drop of temperature due to heat loss to the surroundings and to the incoming gases.

Figures 15 and 16 show the fuel and oxygen profiles. In the inner duct, the air and fuel streams simply mix together and there is no reaction. Therefore at the end of the inner tube, the air-fuel mixture is almost uniformly mixed. The fuel and oxygen profiles show a decay with the passage of the gases through the flame zone in the outer duct. This behaviour is seen to be consistent with the temperature distribution. At the end, all the fuel is consumed and the excess oxygen is left unburnt.

Figures 17 to 21 show the profiles of the species CO, H, H_2, O, and OH. These are intermediate species formed in the reaction zone. Therefore, as expected, the concentrations of these species all have a maximum value within the main reaction zone. The drop in the concentrations of these species from their maximum values as one proceeds further downstream is due to their being converted into the stabler product species CO_2 and H_2O.

Figures 22 and 23 show the profiles of the final product species CO_2 and H_2O. These show a continuous rise and levelling off in the post-flame region. The formation of these two species is consistent with the temperature rise and fuel consumption through the flame zone.

Figures 24 to 27 show the profiles of the NO_x species: N, NO, NO_2

and N_2O. The NO concentration peaks at a point slightly downstream of the main reaction zone. This behaviour is as expected since the formation of NO is governed by kinetically-controlled reactions which are much slower than the hydrocarbon-oxidation reactions which rapidly reach the equilibrium state. After reaching its maximum value, the NO concentration drops slightly due to the dropping temperature.

7.5 Conclusions

The discussion of the results of the two test cases in the preceding sections shows that the results obtained are as expected. Since only one chemically reacting test case was computed, it has not been possible to draw various conclusions about the behaviour of such combustors for different operating conditions. However, the technique for computing such flows has been successfully demonstrated.

It should also be mentioned here that the present results have been obtained with relatively coarse grids. In order to obtain more accurate results, finer grids need to be used; this of course results in increased computer time and storage, but is still within the capabilities of ordinary computers. Finer grids are needed especially in the flame zone in order to obtain better resolution in a region where sharp gradients exist.

8. CONCLUDING REMARKS

The present computer program has been succesffuly used to predict the hydrodynamics and chemistry in a two-concentric-tube combustor. The predictions obtained are qualitatively plausible. Detailed experimental data are required to assess quantitatively the validity of the numerical procedure and the physical hypotheses involved.

In concluding this report, some consideration is given to what further developments would be fruitful. The following improvements may be envisaged to make the program a'proach more towards physical realism.

(a) Turbulence modelling:

The present version of the program incorporates a simple zero-equation model of turbulence. Obviously, this is an over-simplification and a more realistic simulation of turbulence would be to employ the two-equation model employing the kinetic energy of turbulence and its dissipation rate, as the dependent variables of differential equations.

(b) Heat transfer calculations:

In the present program, the modelling of convective and radiative heat transfers has been considerably simplified. In the calculation of convective heat transfer, uniform prescribed Standton number have been employed. A more realistic representation would be to compute the Stanton numbers locally, as done in, for example, Ref. 7.* The extension of the program to achieve this is quite straightforward.

In the calculation of radiative heat transfer, it has been

* Since the writing of this report this has been done. The corresponding update to the program is given as Appendix E.

C-2

assumed that the gas is not participating in the heat transfer process. The incorporation of a four-flux model of radiation (e.g. Ref. 8) would permit a more realistic simulation of the radiation process and would permit the absorption and scattering of radiation by the gas to be accounted for in a simple way. A further refinement would be to compute the distribution of radiation energy in wavelength space; and to allow for the multiple interactions between different parts of the combustion chamber which are the special features of the Hottel-Sarofim (Ref. 9) method. Although the extension of the present code to include these refinements is conceptually straightforward, it should be pointed out that these extensions would result in a considerable increase of both computer storage and processing times.

(c) Sophisticated chemical-kinetic models

The consideration of detailed hydrocarbon-air kinetics as distinct from a simple one-step Arrhenius expression together with the detailed NO_x-kinetics scheme used in the present work would give a more accurate prediction of NO_x-emissions. It is a simple matter to enlarge the chemical-kinetic sophistications of the present program; all that is required is to enlarge the storage requirements of the program, to extend the limits of some DO-loops, and to supply additional coding for the coupling of the species and energy equations. However, this again results in a manifold increase of computer processing time and fine-grid computations with sophisticated chemical kinetics are likely to be prohibitively expensive.

9. REFERENCES

1. Pun W M and Spalding D B, "A general computer program for two dimensional elliptic flows", Imperial College, London, Mechanical Engineering Department, Report No. HTS/76/2, 1976.

2. Gordon S and McBride B, "Computer program for calculation of complex chemical equilibrium compositions", NASA SP-273, 1971.

3. Pratt D T and Wormeck J, "CREK : A computer program for calculation of chemical reaction equilibrium and kinetics in laminar or turbulent flows", Washington State University, Pullman, Department of Mechanical Engineering, Report No. WSU-ME-TEL-76-1, 1976.

4. Patankar S V and Spalding D B, "A calculation procedure for heat, mass and momentum transfer in three-dimensional parabolic flows", Int. J. Heat Mass Transfer, vol 15, p.1787, 1972.

5. Spalding D B, "Basic equations of fluid mechanics and heat and mass transfer and procedures for their solution", Imperial College, London, Mechanical Engineering Department, Report No. HTS/76/6, 1976.

6. Baulch D L, Drysdale D D, Horne D G and Lloyd A C, "Evaluated kinetic data for high temperature reactions, Volume 2", Butterworths, London, 1973.

7. Spalding D B, "GENMIX: A general computer program for two-dimensional parabolic phenomena", Imperial College, London, Mechanical Engineering Department, Report No. HTS/77/9, 1977.

8. Lockwood F C and Spalding D B, "Prediction of a turbulent reacting flow with significant radiation", Published in Proc. Colloques d'Evian, J. de Physique, 1971.

9. Hottel H C and Sarofim A F, "Radiative transfer", McGraw-Hill, New York, 1967.

10. Elghobashi S, Spalding D B and Srivatsa S K, "Prediction of hydrodynamics and chemistry of confined turbulent methane-air flames with attention to formation of oxides of nitrogen", NASA CR-135179, 1977.

11. Bird R B, Stewart W E and Lightfoot E N, "Transport phenomena", Wiley, New York, 1960.

12. Rohsenow W M and Hartnett J P, "Handbook of heat transfer", McGraw-Hill, New York, 1973.

13. Jayatillaka C V L. "The influence of Prandtl number and surface roughness on the resistance of the laminar sub-layer to momentum and heat transfer". Progress in Heat and Mass Transfer, Vol. 1, Ed. by Grigull U and Hahne E, Pergamon Press, London.

10. NOMENCLATURE

Note: Some symbols are defined and used locally in the report; these are not included in the list below:

Symbol	Meaning
a	Cell area
a_{ij}^{L}	Number of kg - atoms of element i per kg mole of species j.
A_i, B_i, C_i, D_i	Coefficients in the finite-difference equations.
A_E, A_N, A_S, A_W	Finite-difference coefficients.
A_j, A_{-j}	Arrhenius pre-exponential factor.
b_j	Number of kg-atoms of element i per kg of mixture.
B_j, B_{-j}	Exponent on temperature in Arrhenius rate expression.
C	Convection mass flux.
C, C_p	Specific heat at constant pressure of the mixture.
$C_{p,j}$	Constant-pressure specific heat of chemical species j.
$D_{1,i}$, $D_{1,0}$, $D_{2,i}$, $D_{2,0}$, D_f	Dimensions of combustor (See Fig. 1).

Symbol	Meaning
D	Diffusion mass flux.
e_1, e_2	Emissivities; 1=inner tube; 2=outer tube.
E	Activation energy.
E	Constant in wall function.
f	Mixture fraction.
f_{st}	Stoichiometric value of mixture fraction.
g_j	Ideal-gas partial molal specific Gibb's function of species j, per kg-mole.
h	Convection heat transfer coefficient.
$\hat{h}$	Stagnation enthalpy.
h_j	Enthalpy of chemical species j.
h_{mix}	Mixture enthalpy (sensible + chemical).
J_{diff}	Diffusion mass flux.
J_j	Diffusion mass flux.
k	Thermal conductivity.
k_b	Backward reaction rate constant.
k_f	Forward reaction rate constant.
K_c	Equilibrium constant.
L_1, L_2, L_3	Dimensions of combustor (see Fig. 1).
m_{ao}	Air flow rate.
m_{fo}	Fuel flow rate.
m_{fu}	Mass fraction of unburnt fuel.
m_j	Mass fraction of chemical species j.

Symbol	Meaning
m_{ox}, m_{O_2}	Mass fraction of oxygen.
M	Number of chemical reactions.
n	Mole number.
n'_j	$\equiv \sum_{i=1}^{NS} \alpha'_{ij}$ = Molecularity of forward reaction j.
n''_j	As n'_j, but for backward reaction j.
NLM	Number of elements.
NS	Number of chemical species in the system.
NSE	Number of chemical species whose concentrations are determined by a chemical-equilibrium analysis.
NSK	Number of chemical species whose concentrations are kinetically determined.
p	Pressure.
P	Arrhenius pre-exponential factor.
P_o	Initial pressure.
P_o	Standard atmospheric pressure.
Pr	Laminar Prandtl number.
Pr_{eff}	Effective Prandtl number.
Q	Heat flux.
Q_{rad}	Radiation heat flux.

Symbol	Meaning
r	Radius.
$r_{1,i}, r_{1,0}, r_{2,i}, r_{2,0}, r_f$	Radii corresponding to $D_{1,i}$, $D_{1,0}$, $D_{2,i}$, $D_{2,0}$, D_f respectively (See Fig. 1.).
$r_{1,m}$ and $r_{2,m}$	$=0.5(r_{1,i}+r_{1,0})$ and $0.5(r_{2,i}+r_{2,0})$ respectively.
R	Universal gas constant.
R_j, R_{-j}	Mass rate of creation of species by forward and reverse reactions j, respectively.
s	Shear stress coefficient.
s	Mass of oxygen per unit mass of fuel in stoichiometric combustion.
s_j	Ideal-gas specific entropy of species j.
s_j^o	One-atmosphere value of s_j.
Sc	Schmidt number.
St	Stanton number.
S_u, S_p	Parts of linearised source term.
S_ϕ	Source term of dependent variable ϕ.
T	Temperature.
$T_{act,j}$	Activation temperature for reaction j, i.e. activation energy divided by the universal gas constant.
T_{ao}	Air temperature at initial axial position.
T_{fo}	Fuel temperature at initial axial position.
u	x-direction velocity-component.

Symbol	Meaning
u_{ao}	Air velocity at initial axial position.
u_{fo}	Fuel velocity at initial axial position.
U	Overall heat transfer coefficient.
v	r- or y- direction velocity-component.
$\overline{W}$	Mean molecular weight of gas mixture.
W_j	Molecular weight of chemical species j.
x	Axial distance.
x	Number of kg-atoms of carbon per kg-mole of hydrocarbon fuel.
y	Radial distance.
y	Number of kg-atoms of hydrogen per kg-mole of hydrocarbon fuel.
$Z_{i\ (i=1,7)}$	Coefficients in thermochemical data equations.

Greek Symbols

α'_{ij}, α''_{ij}	Stoichiometric coefficients of species i in chemical reaction j, as a reactant and as a product respectively.
$\bar{\alpha}_j$	Third-body stoichiometric coefficient in reaction j.
α_p	Under-relaxation factor for pressure.
γ	Ratio of specific heats (C_p/C_v).

Greek Symbols	Meaning
Γ_ϕ	Exchange coefficient for dependent variable ϕ.
δ_{ik}	Kronecker delta function.
δx, Δx	Grid distance in x-direction.
κ	Von Karman constant.
$\delta y, \Delta y, \delta r, \Delta r$	Grid distance in r- or y-direction.
η	Under-relaxation parameter.
λ	Thermal conductivity.
μ, μ_{eff}	Effective viscosity.
μ_ℓ	Laminar viscosity.
ξ	Defined as $(m_{fu} - m_{ox}/s)$.
ξ_{fu}	Defined as $(m_{fu})_{inlet}$.
ξ_{ox}	Defined as $-(m_{ox})_{inlet}/s$.
π_i	Lagrange multipliers in Gibbs function minimisation equation.
ρ	Density.
σ	Stefan-Boltzmann constant.
σ_j	Mole numbers of species j, kg-moles j/kg mixture.
σ_j^*	Average of σ_j over adjacent nodes, weighted by respective finite-difference coefficient.
σ_m	Reciprocal of mean molecular weight of gas mixture $\equiv \sum_{i=1}^{NS} \sigma_i$.

Greek Symbols	Meaning
ϕ	Dependent variable.
ϕ	Equivalence ratio.
τ	Shear stress.

Subscripts

b	Fully burnt.
E,N,S,W	East, North, South, West nodes respectively.
$\tilde{h}$	Stagnation enthalpy.
i	i'th location in the grid.
j	Chemical species j.
NW	Near wall node.
pr	Products
P	Grid node P.
Surr	Surroundings.
wall	Wall values.
ϕ	Dependent variable ϕ.
o	Previous iteration value.
∞	Free stream value.
1,i	Inner side of inner tube.
1,0	Outer side of inner tube.

Subscripts	Meaning
2,i	Inner side of outer tube.
2,0	Outer side of outer tube.
*	'Starred' values.

APPENDIX A

ORGANISATION OF THE NASCO II COMPUTER PROGRAM*

A.1 Introduction

The organisation of the computer program will be looked at in detail in this Appendix. Firstly the structure and the interconnections of the different subroutines are described. The subroutines are classified into different categories depending on the function they serve in the program, and then each of the subroutines is described in detail. In the course of this description are mentioned the program changes necessary to solve problems with different initial and boundary conditions, and also incorporation of alternative physical modelling for properties.

The present program has been derived and developed from the CHAMPION 2/E/FIX program of Pun and Spalding (Ref. 1). The reader is advised to refer to the description of this program for background information.

A.2 Program Structure

A.2.1 Flow Diagram

The structure of the computer program can be represented by the flow diagram given on the next page. Not all the interconnections are shown here, but the ones which are shown are the main ones.

There are 18 subroutines: BLOCK DATA, MAIN, OUTPUT, PRINT, BOUND, SOURCE, WALL, CHEM, SPECE, CALC, CONST, GEOM, ADJUST, FLOWM, COEFF,

---

* NASCO II stands for NASA Surface Combustor, Version II.

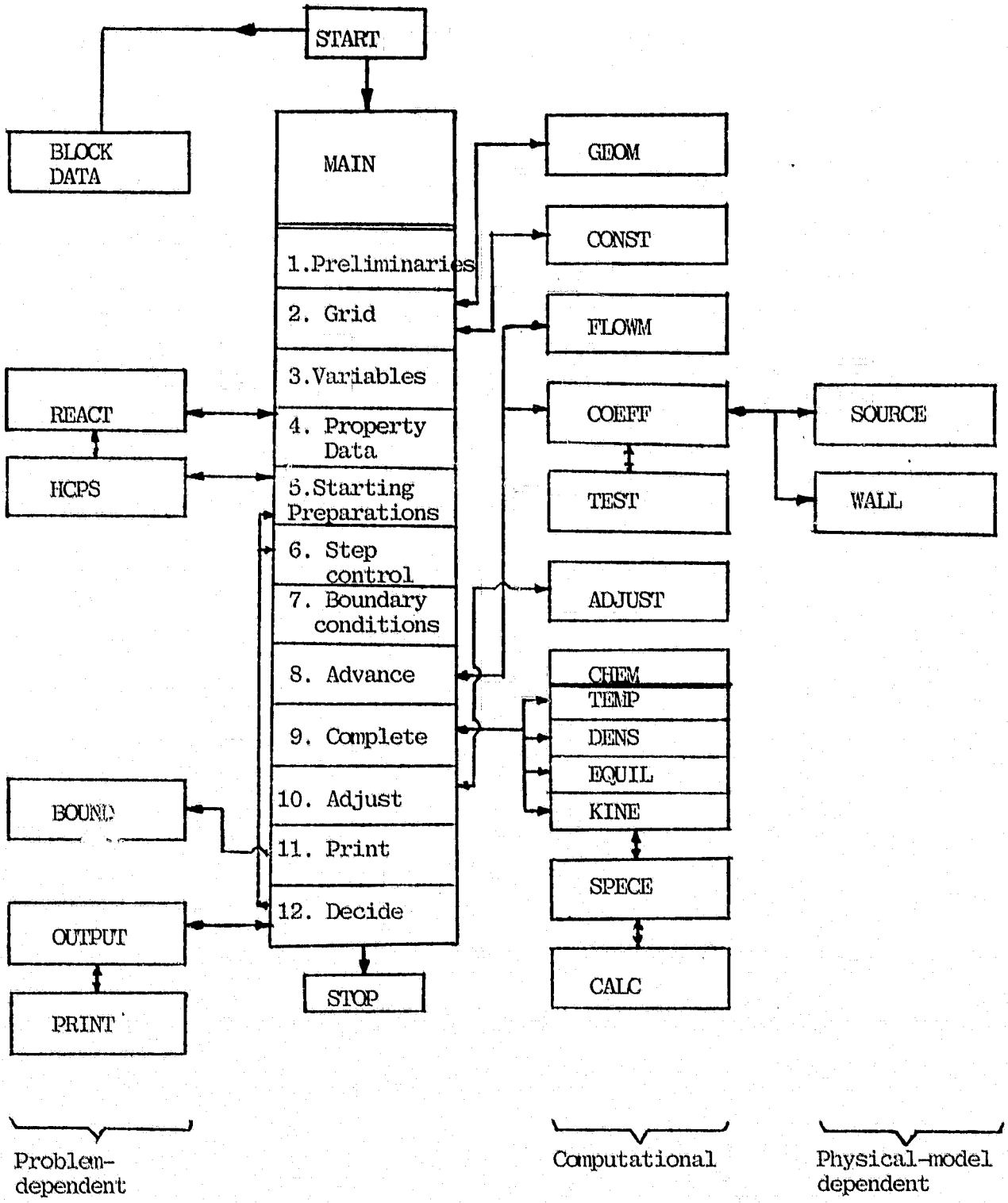


Fig. A.1: FLOW CHART OF NASCO II

TEST, REACT, and HCPS.

The first five are of major concern to the user and they will require at least minor modifications when a new problem is to be tackled. The other subroutines will in general require no modifications. Subroutines SOURCE and WALL embody the physical processes; modifications to these are needed only if alternative physical models are to be considered. Subroutines CHEM, SPECE and CALC relate to chemical-quilibrium and kinetics calculations: these should not be altered. Subroutine REACT is for the input of thermochemical and kinetics data and subroutine HCPS for the calculation of certain thermodynamic quantities. Finally subroutines CONST, GEOM, ADJUST, FLOWM, COEFF and TEST, embody the mechanisms for solving the finite-difference equations; these again should not be altered unless major extensions of the program are envisaged.

A.2.2 Flow of control

Inspection of subroutine MAIN in the flow diagram reveals that, apart from calls to certain subroutines control proceeds from the start to the end of Chapter 5.

The main computation loop is entered at the end of Chapter 5. The loop 5-6-7-8-9-10-11-12-5 is then traversed as many times as there are forward steps and number of iterative sweeps. During the course of this traverse, calls are mode to various subroutines. Finally subroutine OUTPUT is called to print the results as indicated in the flow diagram.

Before describing the various subroutines, a few general comments on the storage of the variables in the program are made.

A.2.3 Storage of variables

The field variables are:

$u\{x,y\}$ [+] ——→ U(I)
$v\{x,y\}$ ——→ V(IV)
$\tilde{h}\{x,y\}$ ——→ H(I)
$f\{x,y\}$ ——→ FM(I)
$m_{fu}\{x,y\}$ ——→ FUE(I)
$m_j\{x,y\}$ ——→ FS(I,J)
$p\{x,y\}$ ——→ P(IP)
$p'\{x\}$ ——→ PP(IY)
$\mu_{eff}\{x,y\}$ ——→ EMU(I)
$T\{x,y\}$ ——→ TEM(I)
$\rho\{x,y\}$ ——→ RHO(I)

In general the storage of $\phi\{x,y\}$ is arranged as follows: for the first row of grid nodes, IX = 1, there are NY values of ϕ, and these values fill the first NY elements of PHI(I); the next NY elements of PHI(I) are filled by the values of ϕ for the next row of nodes, IX = 2. Thus each row of nodes is sequentially stacked to fill the PHI array.

Therefore for a NX*NY grid the total number of elements of the PHI array is NX*NY.

The sizes of the field arrays for the various variables are now summarised:

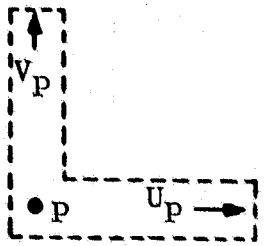
+ The notation $\phi\{x,y\}$ means ϕ is a function of x and y.

Variable	Array Size	Comment
u	(NX-1)*NY	Storage is provided for one less row of cells due to staggering of the grid.
v	NX*(NY-1)	storage is provided for one less strip of fixed IY cells due to staggering of the grid.
ϕ(i.e. $\tilde{h}$, f, m_{fu}, m_j, ρ, T, μ_{eff})	NX*NY	storage is provided for boundary nodes as well as for the control cells.
p	(NX-2)*(NY-2)	storage is provided for internal cells only and not for boundary nodes.
p′	NY	one-dimensional quantity.

The identification of a variable value at a particular nodal location is made by using a simple index determined from the IX, IY position of the variable in the two-dimensional field as follows:

Variables	Fortran Name	Indexing
ϕ(i.e. $\tilde{h}$, f, m_{fu}, m_j, ρ, T, μ_{eff})	See previous page	I=(IX-1)*NY+IY
u	U(I)	I=(IX-1)*NY+IY
v	V(IV)	IV=(IX-1)*NYM1+IY
p	P(IP)	IP=(IX-2)*NYM2+IY-1
p′	PP(IY)	IY

It should be noted that the convention employed for relating the referencing of the staggered velocity nodes to the main nodes is known as the 'L rule', and is shown below:



All of the variable arrays are equivalenced to the single one-dimensional array F. The size of the F array is equal to the sum of all of the variable arrays which are stored in F.

The identification of an element in the F-array is performed using I and an identifier IZERO(JPHI). IZERO(JPHI) indicates the last storage location in the (JPHI-1) th block of the F-array, e.g. EMU(I) in F(I) is:

F(I) = IZERO(JEMU)+IY+(IX-1)*NY.

Other two-dimensional quantities stored in one-dimensional arrays are: VOL, AREAN, AEDDX, ANDDY. These are all geometrical quantities.

A.3 The problem-dependent subroutines, BLOCK DATA, MAIN, OUTPUT, PRINT, and BOUND

A.3.1 BLOCK DATA

This subroutine is used for the input of some data. It consists of nine chapters, the functions of which are explained by their titles; these will now be briefly described.

Chapter 1*. Preliminaries

In this chapter, identification and control parameters are defined. An inspection of the Glossary of Fortran variables in Appendix C, will reveal the function served by the parameters defined here.

Chapter 2. Grid and Geometry

In this chapter, the user must specify the number of transverse and longitudinal grid points and how they are distributed. Geometrical information relating to the dimensions of the combustor is also supplied here.

Chapter 3. Dependent variables

In this chapter, the indices (JU, JV, etc.) defining the location of a variable held in storage in the F-array and the indices (IDN, IDNO, etc.) defining the location of a species stored in the FS-array, are specified. The number and specification of the dependent variables solved for are also given here.

Chapter 4. Property Data

In this chapter, some of the properties of the fluids are specified. Some control parameters relating to properties and processes are also supplied here. Polynomial coefficients AC, AH, ASM, AS1 relating to chemical-equilibrium calculations

* The chapter numbers correspond to those of subroutine MAIN.

are defined here.

Chapter 5. Starting values

In this chapter,. several arrays are initialised to zero; these are the default values. The flow rates, temperatures, fuel and oxygen concentrations of the two incoming streams and the inlet pressure are specified here.

Chapter 7. Boundary conditions

In this chapter, the parameters relating to heat transfer calculations (boundary conditions for the enthalpy equation) are specified.

Chapter 8.Advance

Here the maximum number of iterations to be performed at a given line is specified.

Chapter 11. Print

In this chapter, the parameters controlling the printout of the variables and residual errors are defined.

Chapter 12. Decide

In this chapter, the maximum number of iterative sweeps and the convergence criteria are specified.

A.3.2 Subroutine MAIN

Subroutine MAIN consists of 13 chapters, the functions of which are explained by their titles, and these will now be briefly described.

Chapter 0. Declarations

Here DIMENSIONS AND COMMON statements allocate storage and variable names.

Chapter 1. Preliminaries

Comment cards describing the special features of a particular run are placed in this chapter.

Chapter 2. Grid

In this chapter, a call is made to subroutine CONST(2) to calculate quantities related to the numbers of grid nodes in the x- and y-directions (NX and NY). Next subroutine GEOM is called to calculate grid related quantities.

Chapter 3. Variables

In this chapter comment cards are supplied to state the variables which appear in the differential equations and the auxiliary equations that are to be solved. Subroutine CONST(3) is called to calculate quantities related to the dependent variables.

Chapter 4. Property Data

In this chapter, subroutine REACT is called for the input for thermodynamic and reaction mechanism data. The laminar and turbulent Prandtl/Schmidt numbers of the various dependent variables, and the stoichiometric mixture fraction are also calculated here. The RHO (density) and EMU (viscosity) arrays are initialised with reference values.

Chapter 5. Starting Preparations

The function of this chapter is to:

- call subroutine CONST(5) for the calculation of certain reference indices;
- compute the properties in the inlet fuel and air streams;
- compute the normalising factors for residual errors;
- initialise dependent variable fields:
  - (a) $\tilde{h}$, u, f, m_{fu}, T, species mass fractions in DO-59 loop;
  - (b) NO_x - species in DO-580 and DO-582 loops;
  - (c) μ_{eff} in DO-597 loop;
  - (d) ρ in DO-593 loop;
  - (e) v in DO-590 loop (so as to be in continuity balance with the u specified above).

- call subroutine OUTPUT(1) to print out problem specification;
- call subroutine OUTPUT(2) to print out initial dependent variable fields;
- prepare for the start of a new iterative sweep.

Chapter 6. Step Control

In this chapter the DO-loop limits for the cross-stream TDMA (IYF and IYL) are set and certain indices related to the current IX value and to IYF and IYL are computed.

Chapter 7. Boundary conditions

The boundary condition information is supplied in chapter 7 of BLOCK DATA.

Chapter 8. Advance

This chapter results in the execution of a forward step and the computation of the dependent variables: u and v velocities, enthalpy, mass fraction of unburnt fuel, and mixture fraction.

The sequence of events in the execution of a forward step is:

- a call to COEFF(0) to obtain the diffusion fluxes;
- calls to FLOWM(1) and FLOWM(3) to obtain the convection fluxes;
- calls to COEFF(JU) and ADJUST(3) to perform an integral momentum balance for the current strip of cells (see section 3.3.5). This is performed only on the first iteration at the current line (i.e. when NTRAV=1).
- Finally the DO-800 loop incorporates call to COEFF(JPHI), once for every dependent variable JPHI which is to be solved. Also incorporated in this DO-loop are statements which ensure that when the enthalpy equation is being solved, the cross-stream TDMA extends through both the inner and outer ducts; for other variables, the extent of the field covered by the cross-stream TDMA is as illustrated in Fig. 5.

Chapter 9. Complete

In this chapter, variables which are not obtained directly by the line-by-line TDMA procedure are computed. This is achieved by calls to subroutine CHEM (only for INERT=2, reacting flows):

(a) at ENTRY TEMP to compute the temperature;
(b) at ENTRY DENS to compute the density;
(c) at ENTRY EQUIL for chemical-equilibrium computations (only for IEQUIL=1);
(d) at ENTRY KINE for chemical-kinetics computations (only for KNTCS=1 and ISWEEP>KSWEEP).

For non-reacting flows (INERT=1), control is transformed to statement number 905 and the temperature (if KSOLVE(JTEM). NE.0) is computed in the DO-930 loop. The computation of temperature is as per the discussion presented in Section 3.7.

Next the effective viscosity values are updated in the DO-940 loop. Finally, the influence coefficients DU used in the pressure-correction equation (Sec.3.3.4) are set to zero when dealing with the last column of cells. The reason for this is that the boundary velocities are specified and do not require to be corrected by the pressure-correction equation.

Chapter 10. Adjust

The purpose of this chapter is to perform sectional adjustments in order to achieve integral mass and momentum balances across a strip of cells and also to obtain local continuity balance.

Firstly, overall continuity across the strip is obtained by calls to subroutines FLOWM(2) and ADJUST(1).

Next, local continuity balance is obtained by calls to subroutines FLOWM(1), FLOWM(2), COEFF(JPP) and ADJUST(2); this step involves the solution of the pressure-correction equation.

Finally, subroutine ADJUST(3) is called to obtain integral momentum balance.

Chapter 11. Print

In this chapter, a reference pressure is subtracted from the pressure field to obtain the pressures relative to a selected reference point (IXPREF, IYPREF). Next subroutine BOUND is called, once for each dependent variable solved; this updates the values of the variables on the boundaries for printout purposes.

Chapter 12. Decide

In this chapter the following decisions are taken:

(1) If the maximum sum of the residuals on the current line RSMAX is greater than the convergence criterion RSCHEK and if the number of iterations NTRAV on the line is less than the specified maximum value of NTDMA, the solution on the same line is repeated by transferring control to statement number 80. Otherwise step (ii) below is followed.

(ii) A check is made to see if the sweep has been completed. If yes, then subroutine OUTPUT(3) is called for the printout of residual sources of the variables. If no, then control is transferred to statement 65 for the execution of the next forward step. Subroutine OUTPUT(2) is called for the printout of the field values of the variables every IPRINT sweeps; then step (iii) below is taken.

(iii) Finally, if the largest residual source sum RSMAX in the field is greater than the convergence criterion CCHECK and if the number of sweeps performed ISWEEP is less than the maximum number specified LSWEEP, control is transferred to statement 50 for the start of a new sweep. Otherwise subroutine OUTPUT(2) is called for obtaining the final printout of the dependent variable fields.

A.3.3 Subroutine OUTPUT

Subroutine OUTPUT is divided into four chapters which are now briefly described:

Chapter 1. Preliminaries
This chapter provides by way of DATA statements, values for certain variables used during printout.

Chapter 2. Headings
This chapter is used to obtain some initial printout describing the problem and the input data. Chapters 1 and 2 are activated by CALL OUTPUT(1) from chapter 5 of subroutine MAIN.

Chapter 3. Field values
This chapter prints out the fields of each dependent and auxiliary variable solved for by calling subroutine PRINT. This chapter is activated by CALL OUTPUT(2) from chapter 12 of subroutine MAIN.

Chapter 4. Printout of residual sources and monitoring values
This chapter prints out the residuals of the finite-difference equations for each dependent variable solved and the variable values at the monitoring grid node (IXMON, IYMON). This chapter is activated by CALL OUTPUT(3) from chapter 12 of subroutine MAIN.

A.3.4 Subroutine PRINT

Subroutine PRINT is used to print the field values of the dependent variables. It is divided into three chapters which are described below.

Chapter 1. Preliminaries
In this chapter the appropriate DO-loop limits for the printout

of different variables are set. This is necessary, since as described in Section A.2.3, the storage arrangement is different for different variables.

Chapter 2. Print Titles of variables

As its name indicates, this chapter is used to print the titles of variables stored in the array TITLE.

Chapter 3. Print field values

Finally, in this chapter the field values of the dependent variables are printed.

Subroutine PRINT is called from Chapter 3 of subroutine OUTPUT once for every dependent variable solved and after every IPRINT number of iterative sweeps.

A.3.5 Subroutine BOUND

The function of this subroutine is to update the values of the dependent variables on the boundaries of the integration domain. This updating is a purely 'decorative' exercise and does not influence any computations. Examples of such updating are: setting the centreline value of a dependent variable equal to that at the neighbouring radial grid node; setting the exit plane values equal to those at the neighbouring axial grid node, etc.

Subroutine BOUND consists of a number of sections, one for each dependent variable. The appropriate section is accessed by means of IF-statements at the beginning of the subroutine. The coding is straightforward and easy to interpret with the aid of the comment cards provided.

Subroutine BOUND is called from Chapter 11 of subroutine MAIN, once for each dependent variable being solved.

A.4 The physical-model subroutines, SOURCE and WALL

These two subroutines incorporate the physical models describing the flow situation.

A.4.1 Subroutine SOURCE

The function of this subroutine is to compute the source terms of the dependent variables. It is divided into seven chapters described below. This subroutine is called from subroutine COEFF.

Chapter 1. Preliminaries

In this chapter , IF statements are provided for the transfer of control to any one of the succeeding chapters depending on the dependent variable currently being solved.

Chapter 2. Source terms for u

In this chapter the source terms of the u-momentum equation are computed. The calculation of the general source term as given in Table 1 of chapter 2 is incorporated in the DO-11 loop. For the particular case when both density and viscosity are uniform (as indicated by KRHOMU=0), certain terms are identically zero; the calculation of the source term is then simplified and this is included in the DO 13-loop.

Sources associated with inertial under-relaxation (Section 3.4.2) are also treated in the DO-11 loop.

Finally, at the end of this chapter, programming sequences are provided to include the shear stresses at the inner tube as sources in the u-momentum equation. This follows the discussion of Sections 4.1 and 4.2 and the programming is the Fortran equivalent of the formulae derived in Chapter 6 of Ref 7.

Chapt , 3. Source terms for v

In this chapter the source terms of the v-momentum equation are computed. This chapter is similar to chapter 2.

Chapter 4. Source terms for $\tilde{h}$

In this chapter the source terms of the stagnation enthalpy equation are computed. Inspection of Table 1 of chapter 2 shows that no source terms are normally associated with this equation. The sources in this case are all associated with the heat transfer boundary conditions as discussed in Section 4.3.

Firstly, heat transfer at the inner tube wall is considered (Sec. 4.3.2). The convective and overall heat-transfer coefficients are computed here. Next axial conduction and wall-to-wall radiation fluxes are computed. These are incorporated into the SU-SP terms at the nodes IYWM1, IYW, IYWP1 as per equations (131) to (138).

After this, heat transfer at the outer duct wall is considered (Sec 4.3.3). The programming sequence is similar to that for the inner tube and involves a modification of the SU-SP terms at the nodes NY and NYM1.

Next heat transfer at the end wall is considered. In the DO-425 loop the heat transfer from the wall to the gas is included in the sources of the nodes adjacent to the wall (i.e. IX=NXM1). Finally, in the DO-435 loop the heat transfer to the end wall is considered. Here radial conduction, radiation to the surroundings and free and forced convection to the surroundings are all computed as per the discussion in Section 4.3.

Chapter 5. Source terms for mixture fraction

Inspection of Table 1 of chapter 2 shows that the mixture fraction equation has a zero source term. Consequently, the SU and SP arrays are simply set to zero in the DO-52 loop.

Chapter 6. Source terms for fuel

The computation of the fuel source term is done according to the linearised source-term expressions derived in Section 4.5 of Ref. 10. The programming sequence is contained in the DO- 62 loop and is similar to that provided in Ref. 10.

Chapter 7. Source terms for p'

The source term of the pressure-correction equation is the mass imbalance associated with the 'starred'velocity field (Section 3.3.4). It is therefore computed in the DO-92 loop by adding up the convective fluxes through the four faces of a finite-difference cell.

At the last column of cells (IX=NXM1), the set of equations defining the pressure-corrections is singular since the summation of the S_u-terms of equation (96) for this column is identically zero. This singularity is removed by setting the pressure correction at the IYL node to zero. This is done by the treatment: SU(IYL)=0.0, SP(IYL)=-BIG (a large number). It can be seen from equation (73) that this SU-SP modification will result in a zero pressure-correction at the IYL node.

Finally, the outlet plane boundary condition of uniform pressure is imposed by ensuring the pressure-corrections are zero via the SU-SP modification described above.

A.4.2 Subroutine WALL

The function of this subroutine is the calculation of the quantities required for the modification of the finite-difference coefficients for the nodes adjacent to the duct wall.

On entry into this subroutine, certain indices are computed for use later in the subroutine. Control is then transferred to

statement number 10 if the variable in question is the u-velocity (JPHI=JU). Here some 'reference' values are chosen for density, viscosity, velocity and radius. These are chosen rather arbitrarily. Then if laminar flow is indicated either by KLT being equal to unity or the Reynolds number (based on the 'reference' values) being less than 132.25 ($\equiv 11.5^2$), control is transferred to statement number 19. Here quantities related to laminar flow are computed. Otherwise the turbulent flow section is accessed. The programming sequence here is easy to interpret and is the Fortran equivalent of the formulae derived in chapter 6 of Ref. 7. (see also Section 4.1).

If the variable in question is the v-velocity, then control is transferred to statement number 200. This section is similar to the u-velocity section described above and involves the inclusion of the shear stresses at the end wall in the v-velocity equation.

Subroutine WALL is called from subroutine COEFF once for u-velocity, and once for v-velocity.

A.5 The chemical-model subroutines, CHEM, SPECE, and CALC

These subroutines incorporate the computations involved with the chemistry of the flow. The chemical-kinetics computations are mainly incorporated in subroutines SPECE and CALC which are simplified versions of those given in Ref. 3. These subroutines have been simplified from their original general version to make them more particular to the problem considered here.

A.5.1 Subroutine CHEM

This subroutine is divided into four chapters, each having its own ENTRY and RETURN statements.

Chapter 1. ENTRY TEMP

The function of this subprogram is to compute the temperature of the gas mixture for specified stagnation enthalpy and composition. The method described in Section 3.7 is followed. On entry into this subprogram indices NS1 and NS2 are set appropriate values depending on whether the chemical-kinetics solution is required (KNTCS=1) or not required (KNTCS=0).

The DO-115 loop spans all the internal cross-stream points. Firstly the mass fraction of unburnt fuel is restricted to be no greater than the mixture fraction. Next the concentrations of oxygen and products (considered as one species) are obtained; the concentration of nitrogen is obtained by a process of subtraction in the DO-105 loop. Finally, the DO-110 loop incorporates the Newton-Raphson iteration scheme for temperature. At each iteration the enthalpy (HMIX) and the specific heat (CPMIX) of the equilibrium-product-species are obtained using polynomial fits; thus the computation of each individual species-concentration is avoided. The number of iterations is restricted to NTMAX or less if the normalised change in temperature from one iteration to the next is less than EPST. Both NTMAX and EPST

are defined in Chapter 4 of BLOCK DATA.

Subprogram TEMP is called from subroutine MAIN (Chapter 9).

Chapter 2. ENTRY DENS

The function of this subprogram is to determine the density of the gas mixture. The density is computed in the DO-210 loop which spans all internal cross-stream points. In obtaining the mean molecular weight of the gas mixture, the contribution of the equilibrium-product-species is obtained by means of a polynomial involving temperature.

Subprogram DENS is called from subroutine MAIN (Chapter 9), when INERT equals 2 (reacting flows).

Chapter 3. ENTRY EQUIL

The function of this subprogram is to obtain the concentrations of the equilibrium-product-species. This is done by using polynomial expressions described in Section 3.5.4.

This subprogram is called from subroutine MAIN (Chapter 9), when INERT equals 2 (reacting flows), and IEQUIL equals unity.

Chapter 4. ENTRY KINE

This subprogram is used to obtain the concentrations of the NO_x-species by reference to kinetically-controlled reactions.

Firstly initial estimates for the concentrations of the NO_x-species are specified at the cross-stream plane being solved for and the one downstream of it. This is done by simply setting these values equal to those at the corresponding upstream grid node. This is done in the DO-482 loop which is accessed only during the first iterative sweep for the solution of the NO_x-species (i.e. ISWEEP. EQ. KSWEEP or (KSWEEP+1)); the chemical-kinetics solution is started after other variables have undergone KSWEEP number of iterative sweeps and have stabilized to a certain extent.

The DO-487 loop spans all the internal cross-stream points. In this loop the following operations are performed at each grid node:

- computation of the mole numbers of all the species and storing them in the S2-array (DO-486 loop);

- computation of the weighted averages of the mole numbers of the NO_x-species at the four neighbouring nodes and storing them in the S1-array (DO-488 loop) (this corresponds to σ_1^* of equation (121), Section 3.6.1);

- a call to subroutine SPECE to obtain the chemical-kinetics solution (i.e. mole numbers of the NO_x-species) for temperatures greater than 550^oK;

- conversion of the mole numbers to mass fractions (DO-489 and DO-490 loops);

- adjusting the mass fraction of nitrogen to ensure that all mass fractions add to unity (DO-493 loop).

It will also be noted that should a converged solution be not obtained from subroutine SPECE (as indicated by CONVG=.FALSE.)a warning message is printed out and the NO_x-species-concentrations set equal to the weighted averages of their concentrations at the four neighbouring nodes (DO-402 loop). This is also done for temperatures not greater than 550^oK.

Subprogram KINE is called subroutine MAIN (Chapter 9) when ISWEEP>KSWEEP and KNTCS=1.

A.5.2 Subroutine SPECE

The function of this subroutine is to control the Newton-Raphson iteration procedure for the solution of the chemical-kinetics equations as described in Section 3.6. This subroutine consists of five chapters.

In Chapter 1 the logarithms of the species mole-numbers are computed in the DO-10 loop. The sum of the species mole-numbers and its logarithm are also computed here. The size of the correction matrix, IMAT, is then specified.

In Chapter 2 the main iteration loop (DO-170) is started. The elements of the Newton-Raphson correction matrix are set up by a call to subroutine CALC. Sunsequent statements in Chapter 2 involve the standard Gaussian pivotal elimination solution procedure for the correction matrix.

In Chapter 3 the under-relaxation parameter ETA is computed as described in Ref. 2.

In Chapter 4 the species mole numbers are corrected, the corrections being scaled by the factor ETA.

In Chapter 5 the convergence criterion is applied (Section 3.6.3). If all the species mole numbers have converged to within a user-specified tolerance limit EPSS, the variable CONVG is set equal to .TRUE., and iteration is stopped. Otherwise the same set of operations is repeated until convergence is achieved; the maximum number of iterations being restricted to ITMAX. Values of both ITMAX and EPSS are set in BLOCK DATA (Chapter 4).

Provision is made for printout of several quantities for diagnostic purposes at various stages of this subroutine. This printout is triggered by setting IDEBUG equal to one in Chapter 4 of BLOCK DATA.

Subroutine SPECE is called from subroutine CHEM (ENTRY KINE).

A.5.3 Subroutine CALC

The function of this subroutine is to construct the Newton-Raphson correction matrix for the solution of the chemical-kinetics equations as described in Section 3.6. This subroutine consists of three chapters.

In Chapter 1 all the elements of the correction matrix are initialised to zero. The mixture density is also computed.

In Chapter2 the forward and reverse rates for each reaction are computed in the DO-100 loop. Only three different types of reactions have been considered:

MODE = 1 : $A + B \rightarrow C + D$

MODE = 2 : $AB + M \rightarrow A + B + M$

MODE = 3 : $A + B + M \rightarrow AB + M$

Relevant Fortran statements are provided to determine the reaction type and for MODES 2 and 3, control is transferred to statements 20 and 30 respectively. Subsequent statements compute the correction matrix elements as per the equations given in Section 3.6. All these operations are performed for each reaction in the DO-100 loop.

Chapter 3 completes the calculation of the matrix elements; the term $A_p\sigma_i$ of equation (121) is added to the diagonal elements and the term A_p $(\sigma_i - \sigma_i^*)$ of equation (121) is added to the last column of the correction matrix.

Subroutine CALC is called from Chapter 2 of subroutine SPECE.

A.6 The Computational Subroutines, COEFF, CONST, FLOWM, ADJUST, GEOM and TEST

A.6.1 Subroutine COEFF

This subroutine is used to set up the finite-difference coefficients and solve the finite-difference equations of the various dependent variables. It is divided into five chapters which are described below.

Chapter 1. Preliminaries

The upwind scheme of combining the diffusion and convection terms is defined here by means of an arithmetic statement function. Following this, are IF-statements which transfer control to the appropriate part of the subroutine depending on the variable being solved. Next the diffusion fluxes for the continuity cells on the current line and the one downstream (in the march direction) of it are computed in the DO-158 loop. The statements here are the Fortran equivalents of the equations given in Sec. 3.3.2(c). Care is taken to ensure that the diffusion terms on the boundaries are zero; the boundary effects being introduced through source terms later on.

Chapter 2. Coefficients for u-equation

In this chapter the finite-difference coefficients of the x-momentum equation are computed: (a) in the DO-26 loop when sweeping in the positive-x direction (INC=1); and (b) in the DO-27 loop when sweeping in the negative-x direction (INC=-1). The programming sequences here are simply the Fortran equivalents of the equations given in Section 3.3.3.

Next subroutine SOURCE(JU) is called to obtain the source terms and subroutine WALL to obtain the wall shear stresses. The TDMA coefficients are set up in the DO-290 loop and the back-substitution is done in the DO-292 loop. The residual errors are computed in the DO-291 loop, just before the u-velocities are updated by the

TDMA in the DO-292 loop.

Chapter 3. Coefficients for v-equation

In this chapter the finite-difference coefficients of the r-momentum equation are computed in the DO-36 loop. The coding is similar to that of chapter 2 above. Next subroutine SOURCE(JV) is called for the source terms and subroutine WALL for the wall shear stresses. The application of the TDMA is contained in the DO-390 and DO-392 loops and the residual-error calculation is contained in the DO-391 loop.

Chapter 4. Coefficients for pressure-correction equation

In this chapter the coefficients of the pressure-correction equation are calculated (Sec. 3.3.4) in the DO-46 loop. Here it is ensured that when sweeping in the positive-x direction (INC=1), the west-coefficient AW is zero; since in this case only the east-side u-velocities are affected by the pressure-correction equation. Similarly, when sweeping in the negative-x direction (INC=-1),the east-coefficient AE is set to zero.

Next subroutine SOURCE(JPP) is called to obtain the error mass-source associated with the 'starred' velocity field. Finally the DO-490 and DO-492 loops contain a standard application of the TDMA to obtain the pressure-corrections.

Chapter 5. Phi equation

In this chapter, the finite-difference coefficients of the general ϕ equation are computed in the DO-56 loop (Sec. 3.3.2(c)). Next subroutine SOURCE(JPHI) is called to obtain the source terms. The application of the TDMA is contained in the DO-590 and DO-592 loops and the residual-error calculation in the DO-591 loop.

A.6.2 Subroutine CONST

Subroutine CONST sets constants for use within the program. These are as follows:

- constants related to the total number of x and y grid points;
- constants related to the storage of variables;
- constants setting special points within the field to give pressure reference and monitoring locations.

A.6.3 Subroutine FLOWM

This subroutine is used for the calculation of the convection fluxes for the continuity cells on the current line and the one downstream (in the march direction) of it. The calculation is incorporated in several DO-loops in which the fluxes for the different faces are computed. The reason for splitting the computation into different DO-loops is that on any call to this subroutine only the fluxes which are required on that call may be calculated by accessing the appropriate DO-loop. It will also be noticed that the upwinding of density (e.g. equation (62)) in obtaining the fluxes is performed here.

A.6.4 Subroutine ADJUST

This subroutine is used to perform section-wise mass and momentum balance and cell-wise continuity balance. It is divided into three chapters which are described below.

Chapter 1.Overall-continuity correction

In this chapter section-wise mass balance is achieved. First the integral mass flow rate associated with the 'starred' velocity field is obtained: (a) in the DO-100 loop when sweeping in the positive-x direction (INC=1); and (b) in the DO-1011 loop when

sweeping in the negative-x direction (INC=-1). Then the u-velocities are incremented by a uniform amount DELU in the DO-101 loop to achieve section-wise mass balance.

Chapter 2. Cell-wise continuity correction

In this chapter cell-wise continuity is obtained by correcting the 'starred' velocities u* and v* as per equations (88) and (89) of Section 3.3.4. The pressure is also augmented by an amount equal to the pressure-correction times an under-relaxation factor (as in equation (105) of Section 3.4.2); however the mean pressure level is kept the same so as not to disturb overall momentum balance.

Chapter 3. Overall-momentum correction - SNIP

This chapter incorporates the coding sequences for achieving section-wise momentum balance. This follows the discussion of Section 3.3.5. The average correction to the pressure field ($\Delta\overline{p}$ of equation (97)) is obtained from the DO-302 loop. This $\Delta\overline{p}$ is added to the pressures downstream of the current line in the DO-315, DO-306, DO-308 and DO-309 loops, each of which deals with one particular part of the combustor.

A.6.5 Subroutine GEOM

This subroutine is used to calculate quantities associated with the finite-difference grid. It is divided into three chapters which are described below.

Chapter 1. Radii

In this chapter the radii of the grid nodes are obtained. These are simply equal to the y-coordinates specified in Chapter 2 of BLOCK DATA.

Chapter 2. Cell-node distances

In this chapter the internodal distances DXG (DO-30 loop) and DYG (DO-31 loop) and their reciprocals RDXG and RDYG are calculated. The locations of the u-nodes, XU, are obtained in the DO-32 loop. The distances between the u-nodes, DXU (and their reciprocals, RDXU) are then calculated in the DO-33 loop. Next, the v-node locations are calculated in the DO-34 loop and the distances between these nodes are obtained in the DO-35 loop.

Chapter 3. Cell dimensions

In this chapter the following quantities are calculated:

- lengths of the main cells, SXG, SYG;
- lengths of the u-cells, SXU;
- lengths of the v-cells, SYV;
- the north and east face areas of the main cells, AREAN and AREAE;
- the north and east face areas divided by the internodal distances, ANDDY and AEDDX;
- the volume of each main cell, VOL.

A.6.6 Subroutine TEST

The function of this subroutine is to print information for program testing and debugging. The level of diagnostic detail may be prescribed using the index KTEST (defined in BLOCK DATA) as follows:

KTEST=1 : prints out the geometrical quantities; gives the variable-information; and prints the initial values in the field. This is contained in Chapter 1 of this subroutine.

KTEST=2 : prints out the just calculated values of the dependent variables; their residual sources; the pressure-correction

quantities, as well as all quantities for KTEST=1. This is contained in Chapter 2 of this subroutine.

KTEST=3 : prints out the finite-difference coefficients; the convection and diffusion fluxes, as well as all quantities for KTEST=1 and 2. This is contained in Chapter 3 of this subroutine.

A.7 The Thermochemical property subroutines, REACT and HCPS

These subroutines are concerned with the input and calculation of certain thermodynamic quantities. They have been adpated from Ref. 3 with some changes.

A.7.1 Subroutine REACT

The function of this subroutine is to read, store and process thermochemical data. This subroutine is divided into 4 chapters.

In Chapter 1 certain quantities are defined through data statements. Then follow statements which cause control to be transferred to the appropriate chapter. This depends on which of the words ELEMENTS, THERMO, MECHANISM, or a blank card is encountered in the data deck. Data cards must be in this order, since element data is needed to process thermodynamic data, and thermodynamic data for kinetic-mechanism data. If the chemical-kinetics solution is not required (i.e. KNTCS=0), the kinetic-mechanism data is not read.

Chapter 2 deals with element data. Here one data card is read for each element considered. The contents and format of each data card are given in Table A.1. The total number of elements is designated by NLM.

Chapter 3 deals with thermochemical data. Entry into Chapter 3 occurs after completion of Chapter 2 and via statement number 5. Four data cards are read for each chemical species considered. The contents and format of each data card are given in Table A.2. After the data cards for each species are read, its molecular weight is computed in the DO-24 loop. The total number of species is designated by NS.

The polynomial coefficients Z(I,J,K) for the thermodynamic

TABLE A.1

ELEMENT DATA CARDS

Order of data cards	Contents	Format	Card Columns
First	ELEMENTS	3A4	1 to 8
Any order	One card for each element present in the system. Each card contains:		
	(i) Atomic symbol of element.	A2	1 to 2
	(ii) Atomic weight of element.	F10.6	8 to 17
	(iii) Valence or oxidation state of the element (positive, negative, or zero).	F10.6	18 to 27
Last	Blank card.	-	-

TABLE A.2

THERMOCHEMICAL DATA CARDS

Order of data cards	Contents	Format	Card Columns
First	THERMO	3A4	1 to 6
Any order	A set of four data cards for each species considered. The cards in sequence and contain:		
	(1)(a) Molecular symbol or name of species.	3A4	1 to 12
	(b) Date.	2A3	19 to 24
	(c) Atomic symbols & formula	4(A2,F3.0)	25 to 44
	(d) Phase (gas only, letter G).	A1	45
	(e) Temperature range, degrees K.	2F10.3	46 to 65
	(f) Card number.	I15	80
	(2)(a) Coefficients Z_i(i=1,5) for upper temperature range.	5E15.8	1 to 75
	(b) Card number.	I5	80
	(3)(a) Coefficients Z_6 and Z_7 for upper temperature range, and Z_1, Z_2, and Z_3 for the lower range.	5E15.8	1 to 75
	(b) Card number.	I5	80
	(4)(a) Coefficients Z_i(i=4,7) for the lower temperature range.	4E15.8	1 to 60
	(b) Card number	I20	80
Last	Blank Card.	-	-

TABLE A.3

REACTION MECHANISM DATA CARDS

Order of data card	Contents	Format	Card Columns
First	MECHANISM	3A4	1 to 9
Any order	One data card for each forward (or optionally, reverse) reaction considered. Each card contains:		
	(i) Molecular symbols of upto three reactant species*.	3(2A4)	1 to 24
	(ii) Molecular symbols of upto three product species*.	3(2A4)	25 to 48
	(iii) Exponent B_j**.	F8.3	49 to 56
	(iv) Exponent N_j**.	F8.3	57 to 64
	(v) Activation temperature T_{actj}**.	F8.3	65 to 72
	(vi)(a) For forward reactions, date or comments.	2A4	73 to 80
	(b) For reverse reactions, REVERSE+.	2A4	73 to 79
Last	Blank card.	-	-

*Molecular symbols must be identical to those used in thermochemical data cards.

**Quantities as defined in:

$k_{fj} = 10^{B_j} T^{N_j} \exp(-T_{actj}/T)$ with units

$m^3/$ (kg-mole-sec) for bimolecular reactions,

and $m^6/$ $(kg\text{-mole})^2$sec for termolecular reactions.

+When REVERSE is specified, Columns 1 to 48 are ignored. The data card with reverse rate data must follow immediately the card with the corresponding forward rate data.

properties are divided by the respective molecular weights in the DO-27 loop. Since the present program performs computations with species mass fractions rather than mole numbers, the coefficients will be required in this modified form.

Chapter 4 deals with kinetic-mechanism data. Entry into Chapter 4 occurs after completion of Chapter 3 and via statement number 5. One data card is read for each reaction considered. The contents and format of each data card are given in Table A.3. In statements 33 to 38, the numbers to be stored in the ID (N,J) array are calculated. ID (N,J) is equal to the species index number I (I=1,NS) of the Nth (N=1,4) species which appears in the Jth (J=1,JJ) reaction.

Thus for the reaction

$N + NO = N_2 + O$ (Jth reaction).

ID (1,J)=IDN, ID(2,J)=IDNO, ID(3,J)=IDN2, ID(4,J)=IDO. IDN, IDNO, etc., which identify the different species are defined in Chapter 3 of subroutine BLOCK DATA.

The rest of Chapter 4 is devoted to the computation of the reverse reaction rates, for each forward reaction rate just read in. The reverse reaction constant is obtained from the ratio of the forward reaction rate constant and the equilibrium constant. This is done for fifteen temperatures between 1000°K and 3000°K and the reverse rate parameters are obtained by a least-square linear regression analysis. Details of this computational procedure are given in Ref 3.

If however, the reverse rate data is also supplied on a data card which is subequently read, the calculated reverse rate parameters are overwritten. This is indicated by the statement just preceding statement number 32.

Subroutine REACT is called from Chapter 4 of subroutine MAIN.

A.7.2 Subroutine HCPS

The function of this subroutine is to compute certain thermodynamic quantities (See Section 5.2).

On entry into this subroutine a check is made to see if the temperature is less than 1000°K; this is to decide whether to use the coefficients for the lower (temperature <1000°K) or the higher (temperature ≥1000°K) temperature range. Depending on the value assigned to the variable IHCPS, the following properties are computed:

(i) IHCPS = 1 : The non-dimensional species enthalpy HO(I) and the non-dimensional mixture enthalpy HSUM are computed in the DO-5 loop.

(ii) IHCPS = 2 : The non-dimensional species enthalpy HO(I), the non-dimensional mixture enthalpy HSUM and the non-dimensional mixture specific heat CPSUM are computed in the DO-10 loop.

(iii) IHCPS = 3 : The non-dimensional species enthalpy HO(I), and the non-dimensional species entropy SO(I) at one-atmosphere are computed in the DO-20 loop.

Subroutine HCPS is called from:

(a) Subroutine REACT, Chapter 4, during the computation of reverse reaction rate parameters, with IHCPS=3;

(b) Subroutine MAIN:

- Chapter 5, to obtain inlet enthalpies of the fuel and air streams, with IHCPS=1;

- Chapter 9, to obtain the mixture enthalpy and specific heat, with IHCPS=2;

(c) Subroutine CHEM:

- Chapter 1 (ENTRY TEMP), to obtain the mixture enthalpy and specific heat, with IHCPS=2.

APPENDIX B

LISTING OF THE NASCO II COMPUTER PROGRAM

```
                                                                      BD000010
      BLOCK DATA                                                      BD000020
      COMMON/COMA/ U(480),V(475),H(500),EM(500),FUE(500),FS(500,15),  BD000030
     1 PP(20),TEM(500),P(414),RHO(500),EMU(500),                      BD000040
     1 DXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25), BD000050
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                        BD000060
     3 A(20),AE(20),AH(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),   BD000070
     4 BSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),         BD000080
     5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),    BD000090
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),     BD000100
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),  BD000110
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),         BD000120
     9 AHDDY(500),AREAN(500),VOL(500),                                BD000130
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),           BD000140
     1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),      BD000150
     2 RSREF(25),RSSUM(25),TITLE(25)                                  BD000160
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)    BD000170
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),        BD000180
     1 FLOWFE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))             BD000190
        COMMON/COMB/                                                  BD000200
     1 AK,ARRCON,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,   BD000210
     2 EPST,EQRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,        BD000220
     3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,      BD000230
     4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,        BD000240
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,   BD000250
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,     BD000260
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,   BD000270
     8 LABPHI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,   BD000280
     9 NXM2,NXYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,      BD000290
     X PREXP,PRESS,RELAXP,RF,RFSTM,RSCHEK,RSMAX,R1I,R10,R2I,R20,      BD000300
     1 STOICH,TR,TC,TINY,TMAX,TMIN,UB,UC,WMIX                         BD000310
      LOGICAL CONVG                                                   BD000320
      COMMON /INDEX/ IDCO,IDCO2,IDF,IDH,IDH2,IDH20,IDO,IDOH,IDO2,IDN, BD000330
     1 IDNO,IDNO2,IDN2,IDN20,IEQUIL,IHCPS,IPR,JJ,KNTCS,NA,NLM,        BD000340
     2 NS,NSE1,NSE2,NSK,NSM,NS1,NS2,ID(4,15)                          BD000350
     3/PARAMS/ CONVG,EMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNYBD000360
     5/SPLCES/ASUB(20,3),CPSUM,HSUM,HO(14),SMW(14),SO(14),S1(14),     BD000370
     6 S2(14),Z(2,7,14)                                               BD000380
     7/CEQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,    BD000390
     8 AS1(4,7,2),HDIV,HMAX,HMIN,PEXP(7)                              BD000400
     9/REACTS/BX(15),BX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)      BD000410
      COMMON/ITR/ ALNR1I,ALNR10,ALNR2I,ALNR20,COND,EL3,               BD000420
     1 EMIS10,EMIS2I,EMIS20,EMISXI,EMISXO,REMI,RHOINF,               BD000430
     1 SIGMA,STX1,STX0,ST1I,ST10,ST2I,ST20,TINF,UINF,VINF,WAREA       BD000440
C-----------------------------------------------------------------------BD000450
CHAPTER  1  1  1  1  1  1  1  1  PRELIMINARIES  1  1  1  1  1  1  1  1  BD000460
C-----------------------------------------------------------------------BD000470
      DATA TINYK,TNY/1.0E-20,-46.0517/                                BD000480
      DATA BIG,TINY/1.0E15,1.0E-10/                                   BD000490
      DATA KTEST/0/                                                   BD000500
      DATA KASE/1/                                                    BD000510
C-----------------------------------------------------------------------BD000520
```

```
CHAPTER  2  2  2  2  2  2  2  GRID AND GEOMETRY  2  2  2  2  2  2  2  2 BD000530
C-------------------------------------------------------------------BD000540
      DATA X/0.0,0.03,0.07,0.12,0.17,0.1875,0.1975,0.2025,0.2075,16*.21/BD000550
      DATA Y/0.0,0.0005,0.0015,0.00275,0.00325,0.00375,0.00475,        BD000560
     1 0.00675,0.008,0.009,10*0.009/                                   BD000570
      DATA RF,R11,R10,R21,R20,EL1,EL2/0.001,0.003,0.0035,0.009,0.0105, BD000580
     1 0.2,0.01/                                                       BD000590
      DATA IYW,IXW,IYFUEL/5,7,2/                                       BD000600
      DATA NXMAX,NYMAX/25,20/                                          BD000610
      DATA NX,NY/10,10/                                                BD000620
      DATA KRAD/2/                                                     BD000630
C-------------------------------------------------------------------BD000640
CHAPTER  3  3  3  3  3  3  3  DEPENDENT VARIABLES  3  3  3  3  3  3  3 BD000650
C-------------------------------------------------------------------BD000660
C------ VARIABLES SOLVED BY TDMA                                      BD000670
      DATA JU,JV,JH,JFM,JFUL,JPP/1,2,3,4,5,21/,JS1,JS2/6,20/           BD000680
C------ AUXILIARY VARIABLES                                           BD000690
      DATA JTEM,JP,JRHO,JEMU,JLAST/22,23,24,25,25/                     BD000700
      DATA IDN,IDNO,IDNO2,IDN2O,IDN2,IDF,IDO2,IDCO,IDCO2,IDH,IDH2,IDH2O,BD000710
     1     IDO,IDOH,IPR/1,2,3,4,5,6,7,8,9,10,11,12,13,14,15/           BD000720
      DATA NSK/4/,NSE1/8/,NSE2/14/                                     BD000730
C------ THE NUMBER OF DEPENDENT VARIABLES SOLVED                      BD000740
      DATA NSOLVE/5/                                                   BD000750
      DATA KSOLVE/5*1,15*1,5*1/                                        BD000760
      DATA RELAXP/0.1/                                                 BD000770
      DATA TITLE/'  U ',' V ','ENTH',' FM ','FUEL',                    BD000780
     1           ' H ',' NO ',' NO2',' N2O',' N2 ',                    BD000790
     2           ' F ',' O2 ',' CO ',' CO2',' H ',                     BD000800
     3           ' H2 ',' H2O',' O ',' OH ',' PR ',                    BD000810
     4           ' PP ',' TEM',' P ',' FMU',' EMU'/                    BD000820
C-------------------------------------------------------------------BD000830
CHAPTER  4  4  4  4  4  4  4  4  PROPERTY DATA  4  4  4  4  4  4  4  4 BD000840
C-------------------------------------------------------------------BD000850
C-----S.I. UNITS.                                                     BD000860
C-----THERMODYNAMIC PROPERTIES.                                       BD000870
      DATA NTMAX/10/,EPST/0.001/                                       BD000880
      DATA EPSS/0.001/,ITMAX/50/                                       BD000890
      DATA IDEBUG,KUTCS,KSWEEP/0,1,50/                                 BD000900
      DATA IEQUIL/1/                                                   BD000910
      DATA HDIV,HMAX,HMIN/-8.24E6,-2.16E6,-1.0E7/                      BD000920
      DATA AC1,AC2,AC3,AC4/1.294E-01,9.895E-05,-2.507E-08,2.163E-12/   BD000930
      DATA AH1,AH2,AH3,AH4/-1.579E+03,7.412E-01,-4.360E-04,1.075E-07/  BD000940
      DATA ASM1,ASM2,ASM3,ASM4/3.415E-2,9.316E-6,-7.330E-9,1.716E-12/  BD000950
      DATA AS1/-2.126E+01, 1.293E+02,-4.798E+02, 7.899E+02,            BD000960
     1         -5.981E-01,-5.580E-03, 1.015E-01,-4.767E-01,            BD000970
     2         -3.526E+01, 1.850E+02,-6.634E+02, 1.072E+03,            BD000980
     3         -2.256E+01, 1.089E+02,-3.990E+02, 6.552E+02,            BD000990
     4         -7.981E-01,-4.695E-03, 8.745E-02,-4.284E-01,            BD001000
     5         -3.131E+01, 1.853E+02,-6.487E+02, 1.028E+03,            BD001010
     6         -1.950E+01, 1.140E+02,-4.013E+02, 6.375E+02,            BD001020
     X         -1.396E+01, 3.888E+01,-4.642E+01, 1.943E+01,            BD001030
     1         -6.482E-01, 4.791E-01,-1.261E+00, 4.391E-01,            BD001040
```

```
     2          -2.478E+01, 5.841E+01,-6.959E+01, 2.931E+01,                  BD001050
     3          -1.648E+01, 3.880E+01,-3.982E+01, 1.660E+01,                  BD001060
     4          -8.100E-01, 1.802E-01,-6.237E-01, 2.417E-01,                  BD001070
     5          -2.056E+01, 5.916E+01,-7.200E+01, 3.054E+01,                  BD001080
     6          -1.289E+01, 3.615E+01,-4.415E+01, 1.871E+01/                  BD001090
      DATA PEXP/-0.5,0.0,-0.75,-0.5,0.0,-0.5,-0.25/                          BD001100
      DATA GASCON/8314.4/                                                    BD001110
      DATA TMIN,TMAX/200.0,4000.0/                                           BD001120
      DATA SWITCH,ARRCON,PREEXP/4.0,10000.0,0.01/                            BD001130
      DATA HFU,CMIX,WMIX/4.0E7,1100.0,29.0/                                  BD001140
      DATA EMUREF/1.8E-5/                                                    BD001150
      DATA PRL,PRT/2*1.0,23*0.7,2*1.0,23*0.86/                               BD001160
      DATA AK,EWALL/0.435,9.0/                                               BD001170
      DATA KLT/2/                                                            BD001180
      DATA INERT/2/                                                          BD001190
C-----------------------------------------------------------------------     BD001200
CHAPTER  5  5  5  5  5  5  5  5  STARTING VALUES  5  5  5  5  5  5  5  5BD001210
C-----------------------------------------------------------------------     BD001220
      DATA ISWEEP/0/                                                         BD001230
      DATA ARSL/625*0.0/                                                     BD001240
      DATA RSLINE/625*0.0/                                                   BD001250
      DATA IXMON,IYMON/5,3/                                                  BD001260
      DATA IXPREF,IYPREF/2,2/                                                BD001270
      DATA F,DV/11889*0.0,20*0.0/                                            BD001280
      DATA DIFE,DIFEF,DIFN,DIFNE,DIFW/100*0.0/                               BD001290
      DATA FLOWE,FLOWEE,FLOWN,FLOWNE,FLOWW/100*0.0/                          BD001300
      DATA PRESS/2.0E5/                                                      BD001310
      DATA EMF,EMA/1.4E-5,3.6E-4/                                            BD001320
C-----TWO STREAMS ENTERING - STREAM B IS PURE FUEL, AND STREAM               BD001330
C     C IS AIR.                                                              BD001340
      DATA TB,TC/275.0,275.0/                                                BD001350
      DATA FUB,FUC/1.0,0.0/,OXB,OXC/0.0,0.232/                               BD001360
C-----------------------------------------------------------------------     BD001370
CHAPTER  7  7  7  7  7  7  7  BOUNDARY CONDITIONS  7  7  7  7  7  7  7  BD001380
C-----------------------------------------------------------------------     BD001390
      DATA COND/41.84/,SIGMA/5.67E-8/,                                       BD001400
     1 STXI,STXO/2*0.003/,ST1I,ST1O/2*0.003/,ST2I,ST2O/2*0.003/,             BD001410
     2 UINF/1./,VINF/1./,TINF/300.0/,RHOINF/1.0/                             BD001420
     3,EMIS1O,EMIS2I,EMIS2O,EMISXI,EMISXO/5*0.05/                            BD001430
C-----------------------------------------------------------------------     BD001440
CHAPTER  8  8  8  8  8  8  8  8  8  ADVANCE  8  8  8  8  8  8  8  8  8  BD001450
C-----------------------------------------------------------------------     BD001460
      DATA NTDMA/ 3/                                                         BD001470
C-----------------------------------------------------------------------     BD001480
CHAPTER  11  11  11  11  11  11  11  PRINT  11  11  11  11  11  11  11  BD001490
C-----------------------------------------------------------------------     BD001500
      DATA KINPRI/1/                                                         BD001510
      DATA NUMCOL/10/                                                        BD001520
      DATA IPLRS,IPRINT/50,200/                                              BD001530
C-----------------------------------------------------------------------     BD001540
CHAPTER  12  12  12  12  12  12  12  DECIDE  12  12  12  12  12  12  12 BD001550
C-----------------------------------------------------------------------     BD001560
```

```
      DATA LSWEEP/150/                                                  BD001570
      DATA RSCHEK,CCHECK/0.01,0.005/                                    BD001580
      END                                                               BD001590
```

```
                                                                      MA000010
C-----------------------------------------------------------------------MA000020
CHAPTER 0  0  0  0  0  DECLARATIONS      0  0  0  0  0  0     0 0  0  0  MA000030
C-----------------------------------------------------------------------MA000040
      COMMON/COMA/ U(480),V(475),W(500),FM(500),FUE(500),FS(500,15),    MA000050
     1 FP(20),TEM(500),P(414),RHO(500),EMU(500),                       MA000060
     1 LAG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),  MA000070
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                         MA000080
     3 A(20),AE(20),AW(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),    MA000090
     4 BSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),          MA000100
     5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),     MA000110
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),      MA000120
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCP(20),RVSQ(20),   MA000130
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),          MA000140
     9 AHDDY(500),AREAN(500),VOL(500),                                 MA000150
     X ARSL(25,25),PREF(25),PRL(25),PRT(25),RSLINE(25,25),             MA000160
     1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),       MA000170
     2 NSREF(25),RSSUM(25),TITLE(25)                                   MA000180
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)     MA000190
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),         MA000200
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))              MA000210
      COMMON/COMB/                                                     MA000220
     1 AK,ARSUM,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,     MA000230
     2 EPSI,ERRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,         MA000240
     3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,       MA000250
     4 ISWEEP,IT,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,         MA000260
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,    MA000270
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUF,JH,JLAST,JP,JPP,JRHO,      MA000280
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,    MA000290
     8 LABPHI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,    MA000300
     9 NXM2,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,            MA000310
     X PREEXP,PRESS,RELAXP,RF,RESTM,RSCHEK,RSMAX,R1I,R10,R2I,R20,      MA000320
     1 STOICH,TIN,TC,TINY,TMAX,TMIN,UB,UC,WMIX                         MA000330
      LOGICAL CONVG                                                    MA000340
      COMMON /INDEX/ IDC0,IDC02,IDF,IDH,IDH2,IDH20,IDO,IDOH,IDO2,IDN,  MA000350
     1 IDN0,IDN02,IDH2,IDN20,IEQUIL,IHCPS,IPR,JJ,KNTCS,NA,NLM,         MA000360
     2 NS,NSE1,NSE2,NSK,NSM,NS1,NS2,ID(4,15)                           MA000370
     3/PARAMS/ CONVG,EMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNYMA000380
     5/SPECIES/ASUB(20,3),CPSUM,HSUM,H0(14),SMW(14),S0(14),S1(14),     MA000390
     6 S2(14),Z(2,7,14)                                                MA000400
     7/CONTRL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,     MA000410
     8 AS1(4,7,2),IDIV,IMAX,HMIN,PEXP(7)                               MA000420
     9/REACTS/BX1(15),BX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)      MA000430
      COMMON/HTS/ ALHR1I,ALHR1O,ALHR2I,ALHR2O,COND,EL3,                MA000440
     1 ENIS1O,ENIS2I,ENIS2O,ENISXI,ENISXO,REMI,RHOINF,                 MA000450
     1 SIGMA,STYI,STYO,ST1I,ST1O,ST2I,ST2O,TINF,UINF,VINF,WAREA        MA000460
C-----------------------------------------------------------------------MA000470
CHAPTER 1 1 1 1 1 1 1 1 1 1 1     PRELIMINARIES     1 1 1 1 1 1 1 1 1 1 1MA000480
C-----------------------------------------------------------------------MA000490
C                                                                      MA000500
C-----FLOW IN A TWO-CONCENTRIC-TUBE COMBUSTOR.                         MA000510
C                                                                      MA000520
```

```
C-------------------------------------------------------------------MA000530
CHAPTER 2 2 2 2 2 2 2 2    GRID      2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2MA000540
C-------------------------------------------------------------------MA000550
C ---------------------- QUANTITIES RELATED TO NX AND NY                MA000560
      CALL CONST(2)                                                    MA000570
C---------------------------------------- CALCULATE GRID QUANTITIES     MA000580
      CALL GEOM                                                        MA000590
                                    IF(KTEST.GT.0) CALL TEST(11)       MA000600
C-------------------------------------------------------------------MA000610
CHAPTER 3 3 3 3 3 3 3    VARIABLES   3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 MA000620
C-------------------------------------------------------------------MA000630
C..... VARIABLE INDICES ARE DEFINED IN CHAPTER 3 OF BLOCK DATA.        MA000640
C                                                                      MA000650
C       JU        U-VELOCITY                                           MA000660
C       JV        V-VELOCITY                                           MA000670
C       JH        STAGNATION ENTHALPY                                  MA000680
C       JFM       MIXTURE FRACTION                                     MA000690
C       JFUF      UNBURNT FUEL MASS FRACTION                           MA000700
C       JPP       PRESSURE CORRECTION                                  MA000710
C                                                                      MA000720
C    INDICES OF SECONDARY VARIABLES ARE:                               MA000730
C       JTEM      TEMPERATURE                                          MA000740
C       JP        PRESSURE                                             MA000750
C       JRHO      DENSITY                                              MA000760
C       JEMU      EFFECTIVE VISCOSITY                                  MA000770
C------------------------------ CONSTANTS RELATED TO VARIABLES          MA000780
      CALL CONST(3)                                                    MA000790
                                    IF(KTEST.GT.0) CALL TEST(12)       MA000800
C-------------------------------------------------------------------MA000810
CHAPTER 4 4 4 4 4 4 4 4     PROPERTY DATA     4 4 4 4 4 4 4 4 4 4 4 4 4 MA000820
C-------------------------------------------------------------------MA000830
      CALL REACT                                                       MA000840
      IF (KLT.EQ.1) GO TO 402                                          MA000850
      DO 401 J=1,JPP                                                   MA000860
  401 PREF(J)=PRT(J)                                                   MA000870
      GO TO 404                                                        MA000880
  402 DO 403 J=1,JPP                                                   MA000890
  403 PREF(J)=PRL(J)                                                   MA000900
C------------------------------ PUT REFERENCE VALUES IN FIELD           MA000910
C                                                                      MA000920
  404 RHOREF=PRESS*WMIX/(GASCON*TC)                                    MA000930
      DO 40 I=1,NXYG                                                   MA000940
      RHO(I)=RHOREF                                                    MA000950
40    ENU(I)=ENUREF                                                    MA000960
C                                                                      MA000970
      FSTOIC=OXC/(OXC+STOICH)                                          MA000980
      FSTOIM=1.0-FSTOIC                                                MA000990
      RFST=1.0/FSTOIM                                                  MA001000
C-------------------------------------------------------------------MA001010
CHAPTER 5  5  5  5  5    STARTING PREPARATIONS  5  5  5  5  5  5  5  5 MA001020
C-------------------------------------------------------------------MA001030
C                                                                      MA001040
```

```
      CALL CONST(5)                                                    MA0010500
            EMS=R20-R2I                                                MA0010600
            RMMI=1.0/EMIS21-1.0                                        MA0010700
            R2M=0.5*(R20+R2I)                                          MA0010800
            WAREA=P2M*(R20-R2I)                                        MA0010900
            ALNR1I=ALOG(R(IYW)/R1I)                                    MA0011000
            ALNR10=ALOG(R10/R(IYW))                                    MA0011100
            ALNR2I=ALOG(R2M/R2I)                                       MA0011200
            ALNR20=ALOG(R20/R2M)                                       MA0011300
C                                                                      MA0011400
      PRGSCN=PRESS/GASCON                                              MA0011500
      PRB=1.0-FRB-OXB                                                  MA0011600
      PRC=1.0-FRC-OXC                                                  MA0011700
      WB=OXB/SMW(IDO2)+FUB/SMW(IDF)+PRB/SMW(IDN2)                      MA0011800
      WC=OXC/SMW(IDO2)+FUC/SMW(IDF)+PRC/SMW(IDN2)                      MA0011900
      RHOB=PRGSCN/(WB*TB)                                              MA0012000
      RHOC=PRGSCN/(WC*TC)                                              MA0012100
      FLOB=EMA/6.2831853                                               MA0012200
      FLOC=EMA/6.2831853                                               MA0012300
      FLOWIN=FLOB+FLOC                                                 MA0012400
      IHGPS=1                                                          MA0012500
      IDS1=IDO2                                                        MA0012600
      IDS2=IDO2                                                        MA0012700
      TR=TB                                                            MA0012800
      S2(IDN2)=PRB                                                     MA0012900
      S2(IDF)=FUB                                                      MA0013000
      S2(IDO2)=OXB                                                     MA0013100
      CALL HCPS                                                        MA0013200
      ENTHB=HSUM*GASCON*TB                                             MA0013300
      TR=TC                                                            MA0013400
      S2(IDN2)=PRC                                                     MA0013500
      S2(IDF)=FUC                                                      MA0013600
      S2(IDO2)=OXC                                                     MA0013700
      CALL HCPS                                                        MA0013800
      ENTHC=HSUM*GASCON*TC                                             MA0013900
      UC=FLOC/(0.5*RHOC*(R1I+RF)*(R1I-RF))                             MA0014000
      UB=FLOB/(0.5*RHOB*RF**2)                                         MA0014100
      IYWP1=IYW+1                                                      MA0014200
      IYWM1=IYW-1                                                      MA0014300
C -------  NORMALISING FACTORS.                                        MA0014400
      RSREF(JU)=FLOWIN*UC                                              MA0014500
      RSREF(JV)= RSREF(JU)                                             MA0014600
      RSREF(JH)=ABS(ENTHB*FLOB+ENTHC*FLOC)                             MA0014700
      RSREF(JRM)=FLOWIN                                                MA0014800
      RSREF(JFUF)=FLOWIN                                               MA0014900
      RSREF(JPP)=FLOWIN                                                MA0015000
C-------------- INITIALISE DEPENDENT VARIABLE FIELDS                   MA0015100
      HOUT=(ENTHB*FLOB+ENTHC*FLOC)/FLOWIN                              MA0015200
      FOUT=(FRB+FLOB+FUC*FLOC)/FLOWIN                                  MA0015300
      OXOUT=(OXB*FLOB+OXC*FLOC)/FLOWIN                                 MA0015400
      EM2OUT=(PRB*FLOB+PRC*FLOC)/FLOWIN                                MA0015500
      FUBRAT=AMAX1(TINY,(FOUT-FSTOIC)*RESTM)                           MA0015600
```

```
      PROUT=(FOUT-FUBRNT)*(1.0+STOICH)                                  MA001570
      OXBRNT=AMAX1(TINY,(1.0-FOUT/FSTOIC)*OXC)                          MA001580
      TBRNT=TC+DFU*(FOUT-FUBRNT)/CMIX                                   MA001590
      RHOBRT=PDRSGN*WMIX/TBRNT                                          MA001600
      UOUT=FLOWIN/(0.5*RHOBRT*(R2I+R10)*(R2I-R10))                      MA001610
      DO 59 IY=1,NY                                                     MA001620
      IF(IY.LE.IYFUEL) GO TO 51                                         MA001630
      IF(IY.LT.IYW) GO TO 53                                            MA001640
      IF(IY.GT.IYW) GO TO 55                                            MA001650
      DO 57 IX=1,NXM1                                                   MA001660
      I=IYW+(IX-1)*NY                                                   MA001670
      U(I)=TC                                                           MA001680
   57 TLM(I)=TC                                                         MA001690
      GO TO 59                                                          MA001700
   51 DO 52 IX=1,NXM1                                                   MA001710
      I=IY+(IX-1)*NY                                                    MA001720
      U(I)=UB                                                           MA001730
      H(I)=ENTHR                                                        MA001740
      FR(I)=FUB                                                         MA001750
      FUEL(I)=FUB                                                       MA001760
      TLM(I)=TB                                                         MA001770
      FS(I,IDF2)=PRB                                                    MA001780
      FS(I,IDF)=FUB                                                     MA001790
   52 FS(I,IDF2)=OXB                                                    MA001800
      GO TO 59                                                          MA001810
   53 DO 54 IX=1,NXM1                                                   MA001820
      I=IY+(IX-1)*NY                                                    MA001830
      U(I)=UC                                                           MA001840
      H(I)=ENTHC                                                        MA001850
      FR(I)=FUC                                                         MA001860
      FUEL(I)=FUC                                                       MA001870
      TLM(I)=TC                                                         MA001880
      FS(I,IDF2)=PRC                                                    MA001890
      FS(I,IDF)=FUC                                                     MA001900
   54 FS(I,IDF2)=OXC                                                    MA001910
      GO TO 59                                                          MA001920
   55 DO 56 IX=1,IXW                                                    MA001930
      I=IY+(IX-1)*NY                                                    MA001940
      U(I)=-UOUT                                                        MA001950
      H(I)=HOUT                                                         MA001960
      FR(I)=FOUT                                                        MA001970
      FUEL(I)=FUBRUT                                                    MA001980
      TLM(I)=TBRNT                                                      MA001990
      FS(I,IPF)=PROUT                                                   MA002000
      FS(I,IDF2)=LIN2OUT                                                MA002010
      FS(I,IDF)=FUBRNT                                                  MA002020
      FS(I,IDF2)=OXBRNT                                                 MA002030
      IF(IY.NE.NY) GO TO 56                                             MA002040
      U(I)=0.0                                                          MA002050
      H(I)=TC                                                           MA002060
   56 CONTINUE                                                          MA002070
      IYWP1=IYW+1                                                       MA002080
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
      DO 560 IX=IXWP1,NXM1                                              MA002090
      I=IY+(IX-1)*NY                                                    MA002100
      U(I)=-UOUT                                                        MA002110
      H(I)=HOUT                                                         MA002120
      FF(I)=FOUT                                                        MA002130
      FOE(I)=FOUT                                                       MA002140
      TEB(I)=TC                                                         MA002150
      FS(I,IDF2)=1.0-FOUT-OXOUT                                         MA002160
      FS(I,IDF )=FOUT                                                   MA002170
      FS(I,IDO2)=OXOUT                                                  MA002180
      IF (IY.NE.1Y) GO TO 560                                           MA002190
      U(I)=0.0                                                          MA002200
      H(I)=TC                                                           MA002210
  560 CONTINUE                                                          MA002220
   58 I=IY+NX*2*NY                                                      MA002230
      U(I)=0.0                                                          MA002240
   59 CONTINUE                                                          MA002250
      IX1NY=NXM1*NY                                                     MA002260
      DO 581 IY=1,NY                                                    MA002270
      I=IY+IX1NY                                                        MA002280
      IK=I-NY                                                           MA002290
      TLM(I)=TB                                                         MA002300
  581 H(I)=TEB(I)                                                       MA002310
C-----INITIALIZE NOX-SPECIES ARRAYS.                                    MA002320
      DO 589 IX=2,3                                                     MA002330
      IX1NY=(IX-1)*NY                                                   MA002340
      DO 589 IY=1,1YNM1                                                 MA002350
      I=IY+IX1NY                                                        MA002360
      FS(I,IDF )=1.0E-20                                                MA002370
      FS(I,IDNO)=1.0E-15                                                MA002380
      FS(I,IDO2)=1.0E-20                                                MA002390
  589 FS(I,IDN2O)=1.0E-20                                               MA002400
      IX1NY=(IX-1)*NY                                                   MA002410
      DO 582 IY=IYWP1,NY                                                MA002420
      I=IY+IX1NY                                                        MA002430
      FS(I,IDF )=1.0E-20                                                MA002440
      FS(I,IDNO)=1.0E-15                                                MA002450
      FS(I,IDNO2)=1.0E-20                                               MA002460
  582 FS(I,IDN2O)=1.0E-20                                               MA002470
C                                                                       MA002480
      IF (ISOLVE(JEMH).EQ.0) GO TO 592                                  MA002490
      ENUT=0.96*(FLOH+FLOC)/RII                                         MA002500
      DO 597 IX=1,NX                                                    MA002510
      IX1NY=(IX-1)*NY                                                   MA002520
      DO 597 IY=1,NY                                                    MA002530
      I=IY+IX1NY                                                        MA002540
      EMU(I)=EMUT                                                       MA002550
  597 CONTINUE                                                          MA002560
C                                                                       MA002570
  592 IF (ISOLVE(JRHO).EQ.0) GO TO 595                                  MA002580
      DO 593 IX=1,NXM1                                                  MA002590
      IX1NY=(IX-1)*NY                                                   MA002600
```

```
      DO 593 JY=1,NYP1                                                  MA002610
      I=IY+IX1NY                                                        MA002620
      FPR=1.0-FS(I,IDF)-FS(I,IDN2)                                      MA002630
      VOLIX=FS(I,IDF)/SMW(IDF)+FS(I,IDN2)/SMW(IDN2)+FPR/SMW(IDN2)       MA002640
  593 RHO(I)=DGSCH/(VOLIX*TEM(I))                                       MA002650
C                                                                       MA002660
  595 DO 590 IX=2,NXM1                                                  MA002670
      IXM1=IX-1                                                         MA002680
      IX1NY=IXM1*NY                                                     MA002690
      IX1NY1=IX-1+NYP1                                                  MA002700
      DO 590 IY=2,NYM2                                                  MA002710
      I=IY+IX1NY                                                        MA002720
      IV=IY+1+IX1NY1                                                    MA002730
      ISV=IV-1                                                          MA002740
      IS=I-1                                                            MA002750
      IW=I-NY                                                           MA002760
  590 V(IV)=(V(ISV)*RHO(IS)*AREAN(IS)+AREAF(IY)*(U(IW)*RHO(IW)          MA002770
     1 -U(I)*RHO(I)))/(RHO(I)*AREAN(I))                                 MA002780
C                                                                       MA002790
      CALL OUTPUT(1)                                                    MA002800
C-----------------------------------   PRINT OUT STARTING VALUES        MA002810
      IF (RHOPRI.GT.0) CALL OUTPUT(2)                                   MA002820
C                                                                       MA002830
C****** NEW SWEEP STARTS HERE *****                                     MA002840
C                                                                       MA002850
   50 ISWEEP=ISWEEP+1                                                   MA002860
      IF (MOD(ISWEEP,2).EQ.0) GO TO 500                                 MA002870
      INC=1                                                             MA002880
      IX=1                                                              MA002890
      GO TO 501                                                         MA002900
  500 INC=-1                                                            MA002910
      IX=NX                                                             MA002920
  501 DO 510 J=1,JPP                                                    MA002930
  510 RSSUM(J)=0.0                                                      MA002940
C------------ ------------------------------------------------------   MA002950
CHAPTER 6 6 6 6 6 6 6 6    STEP CONTROL    6 6 6 6 6 6 6 6 6 6 6 6 6   MA002960
C-------------------------------------------------------------------   MA002970
C****** NEW LINE STARTS HERE *****                                      MA002980
C                                                                       MA002990
   65 IX=IX+INC                                                         MA003000
      IXU=IX                                                            MA003010
      IF (INC.EQ.-1) IXU=IX-1                                           MA003020
C                                                                       MA003030
      IF (IX.EQ.IXW) GO TO 6000                                         MA003040
      IYF=2                                                             MA003050
      IYL=NYM1                                                          MA003060
      GO TO 6002                                                        MA003070
 6000 IF (INC.EQ.1) GO TO 6001                                          MA003080
      IYF=IYWP1                                                         MA003090
      IYL=NYM1                                                          MA003100
      GO TO 6002                                                        MA003110
 6001 IYF=2                                                             MA003120
```

```
      IYL=IYW+1                                                          MA003130
 6002 IYLM1=IYL-1                                                        MA003140
      IYLM1=IYL-1                                                        MA003150
      IYLP1=IYL+1                                                        MA003160
      FLOWUP=FLOWIN                                                      MA003170
      IF(IYL.EQ.-1)FLOWUP=-FLOWIN                                        MA003180
      IF(IXU.GT.IXW)FLOWUP=0.0                                           MA003190
      NTRAV=0                                                            MA003200
                                    IXP1=IX+1                            MA003210
                                    IX1NY=(IX-1)*NY                      MA003220
                                    IX1NY1=(IX-1)*NYM1                   MA003230
                                    IX2NY2=(IX-2)*NYM2                   MA003240
                                    IXUP1=IXU+1                          MA003250
                                    IX1NYU=(IXU-1)*NY                    MA003260
                                    IX2NYU=(IXU-2)*NYM2                  MA003270
      DO 66 JP1=3,NLAST                                                  MA003280
66    IXNY(JP1)=IX1NY                                                    MA003290
      IXNY(JU)=IX1NYU                                                    MA003300
      IXNY(JV)=IX1NY1                                                    MA003310
      IXNY(JP)=IX2NY2-1                                                  MA003320
C                                                                        MA003330
C-------------------------------------------------------------------------MA003340
CHAPTER 7 7 7 7 7 7 7     BOUNDARY CONDITIONS   7 7 7 7 7 7 7 7 7 7 7 7 MA003350
C-------------------------------------------------------------------------MA003360
C                                                                        MA003370
C-----SLE BLOCK DATA.                                                    MA003380
C                                                                        MA003390
C-------------------------------------------------------------------------MA003400
CHAPTER 8 8 8 8 8 8 8     ADVANCE       8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 MA003410
C-------------------------------------------------------------------------MA003420
C***** NEW SOLUTION ON A LINE BEGINS HERE *****                          MA003430
C                                                                        MA003440
C      COUNT THE NUMBER OF ADI TRAVERSES ON THE LINE                     MA003450
   80 NTRAV=NTRAV+1                                                      MA003460
      KOUNT(IX)=NTRAV                                                    MA003470
C     SET DIFFUSION TERMS FOR CONTINUITY CELLS ON LINE                   MA003480
      IF(IX.EQ.NX) GO TO 801                                             MA003490
      CALL COEFF(0)                                                      MA003500
      IF(KTEST.GT.2) CALL TEST(41)                                       MA003510
C                                                                        MA003520
C     SET MASS FLOW RATES FOR CONTINUITY CELLS ON LINE                   MA003530
      CALL FLOW(1)                                                       MA003540
      CALL  FLOW(3)                                                      MA003550
      IF(KTEST.GT.2) CALL TEST(40)                                       MA003560
C** SOLVE FOR DEPENDENT VARIABLES **                                     MA003570
C                                                                        MA003580
      IF(NTRAV.GT.1) GO TO 801                                           MA003590
      IF(IYU.EQ.NYM1.OR.IXU.EQ.1) GO TO 801                              MA003600
      ISHIM=0                                                            MA003610
      LABP=1=JU                                                          MA003620
      CALL COEFF(JU)                                                     MA003630
      CALL ADJUST(3)                                                     MA003640
```

```
      IF(KTEST.GT.1) CALL TEST(20)                                          MA003650
  861 ISNIP=1                                                               MA003660
      DO 800 JPHI=1,NSOLVE                                                  MA003670
      IF(KSOLVE(JPHI).EQ.0) GO TO 800                                       MA003680
      IF(JPHI.EQ.JU.AND.(IXU.GE.NXM1.OR.IXU.EQ.1)) GO TO 800                MA003690
      IYFSAV=IYF                                                            MA003700
      IYLSAV=IYL                                                            MA003710
      IF(JPHI.EQ.JH) GO TO 802                                              MA003720
      IF(IX.EQ.IX) GO TO 800                                                MA003730
      GO TO 8 5                                                             MA003740
  802 IYF=2                                                                 MA003750
      IYL=NY                                                                MA003760
      IYFM1=IYF-1                                                           MA003770
      IYLM1=IYL-1                                                           MA003780
      IYLP1=IYL+1                                                           MA003790
  805 LADPHI=JPHI                                                           MA003800
      CALL COEFF(JPHI)                                                      MA003810
                                    IF(KTEST.GT.1) CALL TEST(21)            MA003820
      IYF=IYFSAV                                                            MA003830
      IYL=IYLSAV                                                            MA003840
      IYFM1=IYF-1                                                           MA003850
      IYLM1=IYL-1                                                           MA003860
      IYLP1=IYL+1                                                           MA003870
  800 CONTINUE                                                              MA003880
C-----------------------------------------------------------------------    MA003890
CHAPTER 9   9   9   9   9      COMPLETE   9   9   9   9   9   9   9   9     MA003900
C-----------------------------------------------------------------------    MA003910
      IF(INERT.EQ.1) GO TO 905                                              MA003920
      CALL TEMP(KGOTO)                                                      MA003930
      IF(IX.EQ.NX) GO TO 1250                                               MA003940
      CALL DENS(KGOTO)                                                      MA003950
      IF(IEQUIL.EQ.1) CALL EQUIL(KGOTO)                                     MA003960
      IF(KGTCS.EQ.1.AND.ISWEEP.GE.KSWEEP) CALL KINE(KGOTO)                  MA003970
      GO TO 935                                                             MA003980
  905 IF(KSOLVE(JTEM).EQ.0) GO TO 935                                       MA003990
      PLOSC=PRESS/GASCON                                                    MA004000
      IHCPS=2                                                               MA004010
      NS1=IOH2                                                              MA004020
      NS2=IOX2                                                              MA004030
      DO 940 IY=IYF,IYL                                                     MA004040
      I=IY+IXINY                                                            MA004050
      FUL(I)=FM(I)                                                          MA004060
      FS(I,IOX2)=OXC*(1.0-FM(I))                                            MA004070
      FS(I,IOF )=FUL(I)                                                     MA004080
      FS(I,IOP2)=1.0-FUL(I)-FS(I,IOX2)                                      MA004090
      TK=TEM(I)                                                             MA004100
      ENTH=H(I)/GASCON                                                      MA004110
      DO 910 IS=NS1,NS2                                                     MA004120
  910 SP(IS)=FS(I,IS)                                                       MA004130
      DO 915 JT=1,ITMAX                                                     MA004140
      CALL HCPS                                                             MA004150
      DTEMP=(ENTH/TK-HSUM)/CPSUM                                            MA004160
```

```
      TK=AMIN1(TMAX,TK*(1.0+DTEMP))                                     MA004170
      TK=AMAX1(TMIN,TK)                                                 MA004180
      IF(ABS(DTEMP).LE.EPST) GO TO 925                                  MA004190
  915 CONTINUE                                                          MA004200
      WRITE(6,920) IX,IY,NTMAX,TK,DTEMP                                 MA004210
  920 FORMAT(1H0,10(1H-),2X,31HPOOR CONVERGENCE OF TEMPERATURE/13X,      MA004220
     1 7HAT I =,I3,10H, AND IY =,I3/13X,22HNUMBER OF ITERATIONS =,I3/   MA004230
     2 13X,13HTEMPERATURE =,1PE15.6/13X,7HDTEMP =,1PE15.6/13X,          MA004240
     3 18H***FATAL PROGRAM***/)                                         MA004250
  925 TLM(I)=TK                                                         MA004260
      VMIX=CUE(I)/SMU(IDE)+ES(I,IDO2)/SMW(IDO2)+ES(I,IDN2)/SMW(IDN2)    MA004270
  930 RHO(I)=PDRSLN/(TK*VMIX)                                           MA004280
C                                                                       MA004290
  935 IF (NSOLVE(JEMU).EQ.0) GO TO 945                                  MA004300
      DO 940 IY=IYF,IYL                                                 MA004310
      I=IY+IX1DY                                                        MA004320
  940 EMU(I)=EMUT                                                       MA004330
C                                                                       MA004340
C-----SET DU(IY) FOR IX=2 AND IX=NXM1.                                  MA004350
  945 IF (KOUNT(IX).GT.1) GO TO 999                                     MA004360
      IF (INC.EQ.1.AND.IX.EQ.NXM1) GO TO 994                            MA004370
      GO TO 996                                                         MA004380
  994 DO 995 IY=IYF,IYL                                                 MA004390
  995 DU(IY)=1.0                                                        MA004400
      GO TO 999                                                         MA004410
  996 IF (INC.EQ.-1.AND.IX.EQ.2) GO TO 997                              MA004420
      GO TO 999                                                         MA004430
  997 DO 998 IY=IYF,IYL                                                 MA004440
  998 DU(IY)=0.0                                                        MA004450
  999 CONTINUE                                                          MA004460
C-------------------------------------------------------------------    MA004470
CHAPTER  10   10   10   10   10   ADJUST   10   10   10   10   10   10  MA004480
C-------------------------------------------------------------------    MA004490
C     ---------------            OVERALL CONTINUITY CORRECTION          MA004500
C      ADJUST(1) ADJUSTS ALL THE U-VELOCITIES ON THE LINE IXU FOR       MA004510
C      CONTINUITY ACROSS THE STRIP.                                     MA004520
      IF(IXU.EQ.NXM1.OR.IXU.EQ.1) GO TO 1001                            MA004530
      CALL FLOWM(2)                                                     MA004540
      IF (KTEST.GT.2) CALL TEST(40)                                     MA004550
      CALL ADJUST(1)                                                    MA004560
                                    IF(KTEST.GT.1) CALL TEST(22)        MA004570
C     --------------------------   CELL-WISE CONTINUITY CORRECTION      MA004580
 1001 CALL FLOWM(1)                                                     MA004590
         CALL FLOWM(2)                                                  MA004600
      IF (KTEST.GT.2) CALL TEST(40)                                     MA004610
      LADPHI=JPP                                                        MA004620
      IF (NSOLVE(JPP).EQ.0) GO TO 1000                                  MA004630
      CALL COEFF(JPP)                                                   MA004640
C                                                                       MA004650
C      ADJUST(2) ADJUSTS THE U AND V-VELOCITIES FOR EACH CELL ON        MA004660
C      THE LINE IX FOR CONTINUITY IN THE CELL                           MA004670
      CALL ADJUST(2)                                                    MA004680
```

```
                                    IF(KTEST.GT.1) CALL TEST(23)          MA004690
      IF(IXU.EQ.IXM1.OR.IXU.EQ.1) GO TO 1000                              MA004700
      CALL ADJUST(3)                                                      MA004710
      IF (KTEST.GT.1) CALL TEST(24)                                       MA004720
C                                                                         MA004730
 1000 CONTINUE                                                            MA004740
C-------------------------------------------------------------------------MA004750
CHAPTER 11  11  11  11  11      PRINT      11  11  11  11   11  11   11    MA004760
C-------------------------------------------------------------------------MA004770
C       ALL DECISIONS CONCERNING PRINT-OUT ARE MADE IN CHAPTER 12         MA004780
C       SUBTRACT REFERENCE PRESSURE FROM PRESSURE FIELD                   MA004790
C       VALUES FOR PRINT-OUT                                              MA004800
      PIPREF=P(IPREF)                                                     MA004810
      DO 1100 IP=1,NXYP                                                   MA004820
 1100 P(IP)=P(IP)-PIPREF                                                  MA004830
C       CALL BOUND TO SET BOUNDARY VALUES FOR PRINT-OUT                   MA004840
      DO 1110 J=1,JLAST                                                   MA004850
      LADPHI=1                                                            MA004860
      IF (KSOLVE(J).NE.0) CALL BOUND                                      MA004870
 1110 CONTINUE                                                            MA004880
C                                                                         MA004890
C-------------------------------------------------------------------------MA004900
CHAPTER 12  12  12  12  12    DECIDE      12  12  12  12  12  12  12  12 MA004910
C-------------------------------------------------------------------------MA004920
C                                                                         MA004930
C.....DECIDE WHETHER TO REPLAT THE TRAVERSE ON THE LINE                   MA004940
C                                                                         MA004950
 1250 CONTINUE                                                            MA004960
      RSMAX=ARSL(IXU,1)                                                   MA004970
      DO 1210 J=2,JPP                                                     MA004980
 1210 RSMAX=AMAX1(RSMAX,ARSL(IX,J))                                       MA004990
C                                                                         MA005000
      IF(RSMAX.GT.RSCHEK.AND.NTRAV.LT.NTDMA)  GO TO 80                    MA005010
C     DETERMINE THE SUM OF RESIDUAL SOURCES FOR EACH VARIABLE             MA005020
C                 (SOLVED BY TDMA) ON THE LINE                            MA005030
      RSSUM(1)=RSSUM(1)+ARSL(IXU,1)                                       MA005040
      DO 1220 J=2,JPP                                                     MA005050
 1220 RSSUM(J)=RSSUM(J)+ARSL(IX,J)                                        MA005060
C                                                                         MA005070
C.....DECIDE WHETHER THE SWEEP HAS BEEN COMPLETED                         MA005080
C                                                                         MA005090
      IF (IUC.EQ.-1) GO TO 1230                                           MA005100
      IF(IX.LT.IX)  GO TO 65                                              MA005110
      GO TO 1240                                                          MA005120
 1230 IF (IX.GT.2) GO TO 65                                               MA005130
C                                                                         MA005140
C.....IF SO, PRINTOUT RESIDUAL SOURCES AND VARIABLE VALUES AT             MA005150
C     THE MONITORING LOCATION                                             MA005160
 1240 CALL OUTPUT(3)                                                      MA005170
C     DETERMINE LARGEST RESIDUAL SOURCE SUM IN THE FIELD                  MA005180
      RSMAX=0.0                                                           MA005190
      DO 1200 J=1,JPP                                                     MA005200
```

```
 1200 RSMAX=A AX1(RSMAX,RSSUM(J))                                        MA005210
C                                                                        MA005220
C.....DECISIONS CONCERNING SPECIAL PRINTOUT ARRANGEMENTS                 MA005230
C                                                                        MA005240
      IF(MOD(ISWEEP,IPRINT).EQ.0.AND.ISWEEP.NE.LSWEEP) CALL OUTPUT(2)    MA005250
C                                                                        MA005260
C.....DECIDE WHETHER TO CONTINUE SOLUTION                                MA005270
C                                                                        MA005280
      IF(RSMAX.GT.CCHECK.AND.ISWEEP.LT.LSWEEP)  GO TO 50                 MA005290
C                                                                        MA005300
C.....FINAL PRINTOUT                                                     MA005310
      CALL OUTPUT(2)                                                     MA005320
      STOP                                                               MA005330
      END                                                                MA005340
```

```
      SUBROUTINE OUTPUT(KGOTO)                                                  OU000010
                                                                                OU000020
C-----------------------------------------------------------------------------OU000030
CHAPTER 0  0  0  0  0  0  0    DECLARATIONS    0  0  0  0  0  0  0  0          OU000040
C                                                                               OU000050
      COMMON/CO-A/ U(4800),V(475),H(500),FM(500),FUE(500),FS(500,15),           OU000060
     1 FP(20),TFM(500),P(414),RHO(500),EMU(500),                                OU000070
     1 IXG(25),IXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),           OU000080
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                                  OU000090
     3 A(20),AE(20),AW(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),             OU000100
     4 BSNIP(20),C(20),CSNIP(20),DIFC(20),DIFEE(20),DIFN(20),                   OU000110
     5 DIFUE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),              OU000120
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),               OU000130
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCR(20),RVSQ(20),            OU000140
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),                   OU000150
     9 ANDDY(500),AREAN(500),VOL(500),                                          OU000160
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),                     OU000170
     1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),                OU000180
     2 RSREF(25),RSSUP(25),TITLE(25)                                            OU000190
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)              OU000200
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),                  OU000210
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))                       OU000220
      COMMON/COMB/                                                              OU000230
     1 AR,ARRCON,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,             OU000240
     2 EPSI,ERRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,                  OU000250
     3 FSTOIM,FOB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,                OU000260
     4 ISWEEP,IZ,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,                  OU000270
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,             OU000280
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JJI,JLAST,JP,JPP,JRHO,              OU000290
     7 JS1,JS2,JTEN,JU,JV,KASL,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,             OU000300
     8 LABPRI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,             OU000310
     9 NXM2,NXYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OX6,OXC,PJAY,               OU000320
     X PRECXP,PROCSS,RELAXP,RF,RESTM,RSCHEK,RSMAX,R1I,R1O,R2I,R2O,              OU000330
     1 STOICH,TR,TU,TINY,TMAX,TMIN,UB,UC,WMIX                                   OU000340
      LOGICAL CONVG                                                             OU000350
      COMMON /INDEX/ IDCO,IDCO2,IDF,IDH,IDH2,IDH2O,IDO,IDOH,IDO2,IDN,           OU000360
     1 IDUO,IDU2,IDU2,IDN2O,IEQUIL,IHCPS,IPR,JJ,KNTCS,NA,NLM,                   OU000370
     2 NS,NSE1,NSE2,NSK,NSM,NS1,NS2,ID(4,15)                                    OU000380
     3/PARAMS/ CONVG,EMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNYOU000390
     5/SPECIES/ARUG(20,3),CPSUM,HSUM,HO(14),SMW(14),SO(14),S1(14),              OU000400
     6 S2(14),Z(2,7,14)                                                         OU000410
     7/CEQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,              OU000420
     8 AS1(4,7,2),HDTV,HMAX,HMIN,PEXP(7)                                        OU000430
     9/REACTS/RX(15),RX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)                OU000440
C-----------------------------------------------------------------------------OU000450
CHAPTER 1  1  1  1  1  PRELIMINARIES   1  1  1  1  1  1  1  1  1  1  1        OU000460
C-----------------------------------------------------------------------------OU000470
      DATA KTRIP/9/                                                             OU000480
      DATA BLANK/4H    /,THIRD/4HM   /                                           OU000490
C-----------------------------------------------------------------------------OU000500
CHAPTER 2  2  2  2     HEADINGS     2  2  2  2  2  2  2  2  2  2  2           OU000510
C-----------------------------------------------------------------------------OU000520
```

```
      IF (KGOTO.NE.1) GO TO 3600                                        OU000530
C                                                                       OU000540
C---------------------------------     PROBLEM INFORMATION              OU000550
      RLY=4.0*(FLOB+FLOC)/(EMUREF*R1I)                                  OU000560
      CORAT=FLOB*STOICH/(OXC*(FLOC+TINY))                               OU000570
      WRITE (6,1007)                                                    OU000580
 1007 FORMAT (1H1)                                                      OU000590
      WRITE (6,1013)                                                    OU000600
 1013 FORMAT (11X,51(1H*)/11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,  OU000610
     1 1H*/11X,  51H*          PREDICTION OF HYDRODYNAMICS AND          */OU000620
     2H                *                                               */OU000630
     3H                *         CHEMISTRY OF A TWO-CONCENTRIC-TUBE     */OU000640
     4H                *                                               */OU000650
     5H                *             COMBUSTOR WITH ATTENTION          */OU000660
     6H                *                                               */OU000670
     7H                *              TO POLLUTANT FORMATION           */OU000680
     8 11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/ OU000690
     9 11X,1H*,49X,1H*/11X,1H*,49X,1H*)                                 OU000700
      WRITE (6,1015)                                                    OU000710
 1015 FORMAT(11(,1H*,10X,   40HTHE NASCO II COMPUTER PROGRAM            */OU000720
     1H                *                                               */OU000730
     2H                *                        PREPARED BY,19X,1H*/11X,1H*,49X,OU000740
     3 1H* /11X,1H*, 6X,44HCONCENTRATION, HEAT AND MOMENTUM LTD.        */OU000750
     4 11X,1H*,49X,1H*/11X,1H*,23X,3HFOR,23X,1H*/11X,1H*,49X,1H*/       OU000760
     5H                *  NATIONAL AERONAUTICS AND SPACE ADMINISTRATION */OU000770
     6H                *                                               */OU000780
     7H                *            NASA LEWIS RESEARCH CENTER         */OU000790
     8 11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/ OU000800
     9 11X,1H*,15X,19HCONTRACT  NASW-3077,15X,1H*/11X,1H*,49X,1H*)       OU000810
      WRITE (6,1016) KASE                                               OU000820
 1016 FORMAT(11X,1H*,20),10HAPRIL 1978,19X,1H*/                         OU000830
     1 11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/ OU000840
     2 11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49(1H-),1H*/             OU000850
     3 11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/ OU000860
     4H5H              *             RESULTS FOR TEST CASE,I5,11X,1H*/11X,  OU000870
     5 1H*,49(,1H*/11X,1H*,10X,30HS.I. UNITS ARE USED THROUGHOUT,9X,1H*/OU000880
     6 11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/11X,1H*,49X,1H*/ OU000890
     7 11X,51(1H*))                                                     OU000900
      WRITE (6,1020)                                                    OU000910
 1020 FORMAT (1H1,15HFLOW CONDITIONS/1X,15(1H=))                        OU000920
      IF (KLT.EQ.1) WRITE (6,1021)                                      OU000930
 1021 FORMAT (1H0,4X,14HLAMINAR, KLT=1)                                 OU000940
      IF (KLT.EQ.2) WRITE (6,1022)                                      OU000950
 1022 FORMAT (1H0,4X,16HTURBULENT, KLT=2)                               OU000960
      IF (INERT.EQ.1) WRITE (6,1023)                                    OU000970
 1023 FORMAT (1H0,4X,21HNON-REACTING, INERT=1//)                        OU000980
      IF (INERT.EQ.2) WRITE (6,1024)                                    OU000990
 1024 FORMAT (1H0,4X,20HCHEMICALLY REACTING, INERT=2//)                 OU001000
      WRITE (6,1019)                                                    OU001010
 1019 FORMAT (1H0,8HGEOMETRY/1X,8(1H=))                                 OU001020
      WRITE (6,210) RF,R1I,R1O,R2I,R2O,EL1,EL2                          OU001030
 210  FORMAT(//1X,10H         RF,10H       R1I,10H       R1O,           OU001040
```

```
     110H        RP1,10H        RP0/1X,1P5E10.2//1X,10H        EL1,          OU001050
     210H        EL2/1X,1P2E10.2)                                             OU001060
      WRITE (6,1027) EMF,EMA,UB,UC,TB,TC,PRESS,REY,EQRAT,FLOWIN               OU001070
1027 FORMAT (//1H0,16HINLET CONDITIONS/1X,16(1H=)//5X,                        OU001080
     X 22HFLOW RATE OF FUEL, EMF,12X,1PE10.3//5X,                            OU001090
     Y 21HFLOW RATE OF AIR, EMA,13X,1PE10.3//5X,          27HVELOCITY OFOU001100
     1 FUEL STREAM, UB,7X,1PE10.3//5X,26HVELOCITY OF AIR STREAM, UC,8X, OU001110
     2 1PE10.3//5X,30HTEMPERATURE OF FUEL STREAM, TB,4X,1PE10.3//5X,    OU001120
     3 29HTEMPERATURE OF AIR STREAM, TC,5X,1PE10.3//5X,21HINLET PRESSUREOU001130
     4, PRESS,13X,1PE10.3//5X,15HREYNOLDS NUMBER,19X,1PE10.3//5X,       OU001140
     5 34HOVERALL EQUIVALENCE RATIO, EQRAT  ,1PE10.3//5X,  28HTOTAL MASSOU001150
     6 FLOW RATE, FLOWIN,6X,1PE10.3//)                                  OU001160
      WRITE (6,1091)                                                     OU001170
1091 FORMAT(1H1,53HPOLYNOMIAL COEFFICIENTS FOR THERMODYNAMIC PROPERTIESOU001180
     1./61H 14 COEFFICIENTS ((Z(K,J,I),J=1,7),K=1,2) FOR EACH SPECIFS I.OU001190
     2//)                                                               OU001200
      DO 1088 I=1,NSP2                                                  OU001210
1088 WRITE (6,1082) ASUB(I,1),((Z(K,J,I),J=1,7),K=1,2)                  OU001220
1082 FORMAT (1H0,A4/(3X,1P6E11.3))                                      OU001230
      IF (KOUTS.EQ.0) GO TO 1085                                        OU001240
      WRITE (6,1083)                                                    OU001250
1083 FORMAT (1H1,18HREACTION MECHANISM/1X,18(1H=))                      OU001260
      DO 1061 J=1,JJ                                                    OU001270
      DO 1060 KK=1,6                                                    OU001280
      LL=KK                                                             OU001290
      IF (KK.GT.3) LL=KK-1                                              OU001300
      DATA (KK)=BLANK                                                   OU001310
      IF (KK.EQ.3) GO TO 1060                                           OU001320
      IF (KK.EQ.6) GO TO 1060                                           OU001330
      IDLLJ=IB(LL,J)                                                    OU001340
      IF (IDLLJ.EQ.0) GO TO 1060                                        OU001350
      DATA (KK)=ASUB(IDLLJ,1)                                           OU001360
1060 CONTINUE                                                           OU001370
      IF (IB(2,J).EQ.0) GO TO 1062                                      OU001380
      IF (IB(4,J).EQ.0) GO TO 1062                                      OU001390
      GO TO 1063                                                        OU001400
1062 DATA(3)=THIRD                                                      OU001410
      DATA(6)=THIRD                                                     OU001420
      WRITE (6,1064) J,(DATA(K),K=1,6)                                  OU001430
1064 FORMAT (I3,2H. ,A4,2H+ ,A4,2H+ ,A4,2H= ,A4,2H+ ,A4,2H+ ,A4,       OU001440
     1 1P3E11.3)                                                        OU001450
      GO TO 1061                                                        OU001460
1063 WRITE (6,1065) J,(DATA(K),K=1,6)                                   OU001470
1065 FORMAT (I3,2H. ,A4,2H+ ,A4,2X,A4,2H= ,A4,2H+ ,A4,2X,A4,1P3E11.3)   OU001480
1061 CONTINUE                                                           OU001490
      WRITE (6,1084) (J,BX(J),TEN(J),TACT(J),BX2(J),TEN2(J),TACT2(J),   OU001500
     1                                                      J=1,JJ)OU001510
1084 FORMAT (1H0,2X,24HRATE CONSTANT PARAMETERS/5X,37HRATE CONSTANT =   OU001520
     1 A*T**B*EXP(-TACT/T),10X,15H(T=TEMPERATURE)///17X,12HFORWARD RATE,OU001530
     2 21X,13HBACKWARD RATE//9X,1HA,10X,1HB,8X,4HTACT,9X,1HA,10X,1HB,8X,OU001540
     3 4HTACT/(I3,1H.,1P6E11.3))                                        OU001550
1085 WRITE(6,250) NX,NY,NXMAX,NYMAX                                     OU001560
```

```
      WRITE(6,251) NTDMA,LSWEEP,RSCHEK,CCHECK                          OU001570
250   FORMAT(/1X,10H        NX,10H        NY,10H     NXMAX,10H     NYMAXOU001580
     1/1X,4(I8))                                                       OU001590
  251 FORMAT(/1X,10H     NTDMA,10H    LSWEEP                          OU001600
     1,10H    RSCHEK,10H    CCHECK/1X,2I10,1P2E10.2)                  OU001610
      RETURN                                                           OU001620
C-------------------------------------------------------------------OU001630
CHAPTER 3  3  3  3  3  FIELD VALUES  3  3  3  3  3  3  3  3  3       OU001640
C-------------------------------------------------------------------OU001650
 3000 IF (KGOTO.NE.2) GO TO 4000                                       OU001660
      DO 31 JPHI=1,JLAST                                               OU001670
      IF(JPHI.EQ.JPP) GO TO31                                          OU001680
      IF(KSOLVE(JPHI),EQ.0) GO TO 31                                   OU001690
      CALL PRINT(JPHI)                                                 OU001700
31    CONTINUE                                                         OU001710
      KTRIP=0                                                          OU001720
      RETURN                                                           OU001730
C-------------------------------------------------------------------OU001740
CHAPTER 4  4  4  4   PRINT OUT OF RESIDUALSOURCES AND MONITORING VALUES OU001750
C-------------------------------------------------------------------OU001760
 4000 IF (KGOTO.NE.3) RETURN                                           OU001770
      IF(MOD(ISWEEP,IPLRS).NE.0) GO TO 4140                            OU001780
      KTRIP=0                                                          OU001790
      WRITE(6,4100)ISWEEP,ISWEEP,(TITLE(K),K=1,NSOLVE),TITLE(JPP)      OU001800
      DO 418 IX=2,NXM1                                                 OU001810
418   WRITE(6,4102)IX,KOUNT(IX),(RSLINE(IX,J),J=1,NSOLVE),RSLINE(IX,JPP)OU001820
      WRITE(6,4104)IXMON,IYMON,(TITLE(K),K=1,NSOLVE),TITLE(JP)         OU001830
      DO 417 J=1,NSOLVE                                                OU001840
      I=IMON(J)+IZERO(J)                                               OU001850
  417 STORE(J)=F(I)                                                    OU001860
      I=IMON(JP)                                                       OU001870
      WRITE(6,4112)ISWEEP,(STORE(J),J=1,NSOLVE),F(I)                   OU001880
 4140 IF(KTRIP.EQ.0) WRITE(6,4113) (TITLE(K),K=1,NSOLVE),TITLE(JPP)    OU001890
      KTRIP=1                                                          OU001900
      WRITE(6,4112)ISWEEP,(RSSUM(J),J=1,NSOLVE),RSSUM(JPP)             OU001910
 4100 FORMAT(/1X,10HSWEEP NO. ,I3,2X,80(1H=),4X,10HSWEEP NO. ,I3//1X,  OU001920
     16HALGEBRAIC SUM OF RESIDUAL SOURCES AT EACH LINE--RSLINE(IX,JPHI)OU001930
     2/1X,13HIX  NO. TRAVS,2X,10(3X,A4,3X))                           OU001940
 4102 FORMAT(1X,I2,6X,I2,3X,1P10E10.2)                                 OU001950
 4104 FORMAT(/1X,31HVALUES AT MONITORING LOCATION (,I2,1H,,I2,1H)/     OU001960
     16X,6HISWEEP,3X,10(3X,A4,3X))                                    OU001970
 4112 FORMAT(6X,I3,6X,1P10E10.2)                                       OU001980
 4113 FORMAT(/1X,38HSUM OF ABS. VALUES OF RSLINE(IX,JPHI)-/            OU001990
     1 6X,6HISWEEP,3X,10(3X,A4,3X))                                   OU002000
      RETURN                                                           OU002010
      END                                                              OU002020
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
      SUBROUTINE PRINT(LPHI)                                                    PR000010
C-----------------------------------------------------------------------------PR000020
CHAPTER  0   0   0   0   0   DECLARATIONS  0   0     0     0                    PR000030
C                                                                               PR000040
      COMMON/COMA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),            PR000050
     1 PP(20),TRM(500),P(414),RHO(500),EMU(500),                                PR000060
     1 DXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),           PR000070
     2 STORL(25),SXG(25),SXU(25),X(25),XU(25),                                  PR000080
     3 A(20),F(20),AN(20),ARLAE(20),AS(20),ASNIP(20),AW(20),B(20),              PR000090
     4 BSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),                   PR000100
     5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),              PR000110
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),               PR000120
     7 RDYC(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),            PR000130
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),                   PR000140
     9 AHDDY(500),AREAN(500),VOL(500),                                          PR000150
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),                     PR000160
     1 IEW(25),ILAST(25),IMON(25),IXMY(25),IZERO(25),KSOLVE(25),                PR000170
     2 RSREF(25),RSSUM(25),TITLE(25)                                            PR000180
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)              PR000190
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),                  PR000200
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))                       PR000210
      COMMON/COMB/                                                              PR000220
     1 AK,ARROW,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,              PR000230
     2 EPSI,ERRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,                  PR000240
     3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,                PR000250
     4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1MY,IX1MYU,                  PR000260
     5 IX1MY1,IX2MYU,IX2MY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,             PR000270
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,               PR000280
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,             PR000290
     8 LABFLI,LSWEEP,MSOLVE,MTDMA,MTMAX,MTRAV,NUMCOL,NX,NXMAX,NXM1,             PR000300
     9 NXM2,NXYMAX,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,              PR000310
     X PRLEXP,PRESS,RELAXP,RF,RFSTM,RSCHEK,RSMAX,R1I,R1O,R2I,R2O,               PR000320
     1 STOICH,TB,TC,TINY,TMAX,TMIN,UB,UC,WMIX                                   PR000330
      LOGICAL CONVG                                                             PR000340
      COMMON /INDEX/ IDCO,IDCO2,IDF,IDH,IDH2,IDH2O,IDO,IDOH,IDO2,IDN,           PR000350
     1 IDNO,IDNO2,IDM2,IDN2O,IEQUIL,IHCPS,IPR,JJ,KNTCS,NA,NLM,                  PR000360
     2 NS,NSEL,NSE2,NSK,NSM,NS1,NS2,ID(4,15)                                    PR000370
     3/PARAMS/ CONVG,EMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNY        PR000380
     5/SPECIES/ASUB(20,3),CPSUM,HSUM,HO(14),SMW(14),SO(14),S1(14),              PR000390
     6 S2(14),Z(2,7,14)                                                         PR000400
     7/CEQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,              PR000410
     8 AS1(4,7,2),HDIV,HMAX,HMIN,PEXP(7)                                        PR000420
     9/REACTS/BX(15),BX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)                PR000430
C-----------------------------------------------------------------------------PR000440
CHAPTER 1  1   1   1    PRELIMINARIES  1   1   1   1   1   1   1               PR000450
C                                                                               PR000460
      JPHI=LPHI                                                                 PR000470
      IF(JPHI.EQ.JP) GO TO 12                                                   PR000480
C-------------------------------------  FOR ALL PHI'S EXCEPT P                  PR000490
      KOLUM1=1                                                                  PR000500
      KOLUM2=NUMCOL                                                             PR000510
```

```
10    LIMIT1=KOLUM1                                                    PR000530
      LIMIT2=KOLUM2                                                    PR000540
      LTOP=IZERO(JPHI)                                                 PR000550
      LBOT=1                                                           PR000560
      IF(JPHI.NE.JU) GO TO 11                                          PR000570
C-----------------------------------------------------      U          PR000580
      IF(LIMIT1.GT.NXM1) LIMIT1=NXM1                                   PR000590
      IF(LIMIT2.GT.NXM1) LIMIT2=NXM1                                   PR000600
      GO TO 20                                                         PR000610
C-----------------------------------------------------    OTHER PHI'S  PR000620
11    IF(LIMIT1.GT.NX) LIMIT1=NX                                       PR000630
      IF(LIMIT2.GT.NX) LIMIT2=NX                                       PR000640
      GO TO 20                                                         PR000650
C-----------------------------------------------------    FOR  P       PR000660
12    KOLUM1=2                                                         PR000670
      KOLUM2=NUMCOL+1                                                  PR000680
13    LIMIT1=KOLUM1                                                    PR000690
      LIMIT2=KOLUM2                                                    PR000700
      IF(LIMIT1.GT.NXM1) LIMIT1=NXM1                                   PR000710
      IF(LIMIT2.GT.NXM1) LIMIT2=NXM1                                   PR000720
      LTOP=NY-1                                                        PR000730
      LBOT=2                                                           PR000740
C-----------------------------------------------------------------------PR000750
CHAPTER 2  2  2  2  2   PRINT TITLE OF VARIABLES   2   2  2  2  2  2  2PR000760
C                                                                      PR000770
20    WRITE(6,200) TITLE(JPHI),TITLE(JPHI)                             PR000780
200   FORMAT(/1X,15HFIELD VALUES OF,1X, A4,2X,22(1H-),A4,22(1H-))      PR000790
C-----------------------------------------------------------------------PR000800
CHAPTER 3   3    3    3    PRINT FIELD VALUES   3   3   3   3   3   33 PR000810
C                                                                      PR000820
      DO 39 IIY=LBOT,LTOP                                              PR000830
      IY=LTOP-IIY+LBOT                                                 PR000840
      DO 30 IX=LIMIT1,LIMIT2                                           PR000850
      IF(JPHI-JU)301,31,301                                            PR000860
301   IF(JPHI-JV)302,32,302                                            PR000870
302   IF(JPHI-JP)303,33,303                                            PR000880
 303  CONTINUE                                                         PR000890
31    I=IY+(IX-1)*NY                                                   PR000900
      GO TO 3000                                                       PR000910
32    I=IY+(IX-1)*NYM1                                                 PR000920
      GO TO 3000                                                       PR000930
33    I=IY-1+(IX-2)*NYM2                                               PR000940
3000  I=I+IZERO(JPHI)                                                  PR000950
30    STORE(IX)=F(I)                                                   PR000960
      IF(JPHI-JV)310,311,310                                           PR000970
310   WRITE(6,3100)IY,Y(IY),(STORE(IX),IX=LIMIT1,LIMIT2)               PR000980
      GO TO 39                                                         PR000990
311   WRITE(6,3101)IY,YV(IY),(STORE(IX),IX=LIMIT1,LIMIT2)              PR001000
39    CONTINUE                                                         PR001010
      IF(JPHI-JU)320,321,320                                           PR001020
320   WRITE(6,3102)(IX,X(IX),IX=LIMIT1,LIMIT2)                         PR001030
      GO TO 340                                                        PR001040
```

```
321   WRITE(6,3103)(IX,XU(IX),IX=LIMIT1,LIMIT2)                          PR001050
360   IF(JPHI.EQ.JU) GO TO 350                                           PR001060
      IF(JPHI.EQ.JP) GO TO 350                                           PR001070
C-----------------------------   FOR ALL PHI'S OTHER THAN U AND P        PR001080
      IF(LIMIT2.EQ.NX) RETURN                                            PR001090
      KOLUM1=KOLUM1+NUMCOL                                               PR001100
      KOLUM2=KOLUM2+NUMCOL                                               PR001110
      GO TO 10                                                           PR001120
C-------------------------------------------------   FOR U AND P        PR001130
350   IF(LIMIT2.EQ.NXM1) RETURN                                          PR001140
      KOLUM1=KOLUM1+NUMCOL                                               PR001150
      KOLUM2=KOLUM2+NUMCOL                                               PR001160
      IF(JPHI.EQ.JU) GO TO 10                                            PR001170
      GO TO 13                                                           PR001180
3100  FORMAT(1X,1X,5HY(,I2,2H)=,1PE9.3,2X,10(1PE9.2,1X))                 PR001190
3101  FORMAT(1X,3HYV(,I2,2H)=,1PE9.3,2X,10(1PE9.2,1X))                   PR001200
3102  FORMAT(/5X,5HX(IX), 9X,10(I2,1H=,F6.3,1X)//)                       PR001210
3103  FORMAT(/5X,6HXU(IX), 8X,10(I2,1H=,F6.3,1X)//)                      PR001220
      END                                                                PR001230
```

```
                                                                        B0000010
      SUBROUTINE BOUND                                                  B0000020
      COMMON/COMA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),    B0000030
     1 TM(20),TEM(500),P(414),RHO(500),EMU(500),                        B0000040
     1 XG(25),XU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),     B0000050
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                          B0000060
     3 A(20),C(20),AH(20),AREAC(20),AS(20),ASNIP(20),AW(20),B(20),      B0000070
     4 CSUIP(20),C(20),CSNIP(20),DIFE(20),DIFLE(20),DIFN(20),           B0000080
     5 DIFNC(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),      B0000090
     6 FLOWL(20),FLOWEL(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),       B0000100
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCR(20),RVSQ(20),    B0000110
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),           B0000120
     9 AHDDY(500),ARFAH(500),VOL(500),                                  B0000130
     X ARSL(25,25),PREF(25),PRL(25),PRT(25),RSLINE(25,25),              B0000140
     1 IEW(25),ILAST(25),IMON(25),IXDY(25),IZERO(25),KSOLVE(25),        B0000150
     2 KSREF(25),RSSUM(25),TITLE(25)                                    B0000160
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)      B0000170
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),          B0000180
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))               B0000190
      COMMON/COMB/                                                      B0000200
     1 AK,ARRAY,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,      B0000210
     2 EPSI,ERRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,          B0000220
     3 ISTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,        B0000230
     4 ISWEEP,IX,IXMON,IXPRLF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,          B0000240
     5 IX1UY1,IX2UYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,     B0000250
     6 IYPRET,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,       B0000260
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,     B0000270
     8 LABPHI,LSWEEP,MSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,     B0000280
     9 NXM2,NYYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,        B0000290
     X RELXP,PRESS,RELAXP,RF,RFSTM,RSCHEK,RSMAX,R11,R10,R21,R20,        B0000300
     1 STOICH,TB,TC,TINY,TMAX,TMIN,UB,UC,WMIX                           B0000310
C-----------------------------------------------------------------------B0000320
C            UPDATE VALUES ON BOUNDARIES FOR PRINTOUT PURPOSES          B0000330
C-----------------------------------------------------------------------B0000340
      JPHI=LABPHI                                                       B0000350
      IF (JPHI.EQ.JU)     GO TO 10                                      B0000360
      IF (JPHI.EQ.JH)     GO TO 40                                      B0000370
      IF (JPHI.EQ.JFM)    GO TO 50                                      B0000380
      IF (JPHI.EQ.JFUE)   GO TO 60                                      B0000390
      IF (JPHI.EQ.JTEM)   GO TO 110                                     B0000400
      IF (JPHI.EQ.JP)     GO TO 120                                     B0000410
      IF (JPHI.EQ.JRHO)   GO TO 130                                     B0000420
      IF (JPHI.EQ.JEMU)   GO TO 140                                     B0000430
      RETURN                                                            B0000440
C                                                                       B0000450
C-------------------------------------    U AT AXIS OF PIPE             B0000460
   10 I=1+IX1NYU                                                        B0000470
      U(I)=U(I+1)                                                       B0000480
C-------------------------------------    UPDATE U AT PIPE EXIT         B0000490
      IF  (IXU.NE.2) RETURN                                             B0000500
      IF  (INC.EQ.1) RETURN                                             B0000510
      DO 12 IY=IYWP1,NYM1                                               B0000520
```

```
      I=IY+IX1NYU                                                    B0000530
      IW=I-NY                                                        B0000540
   12 U(IW)=U(I)                                                     B0000550
      RETURN                                                         B0000560
C                                                                    B0000570
C-----UPDATE U ON BOUNDARIES.                                        B0000580
C-----AT PIPE AXIS.                                                  B0000590
   40 I=1+IX1NY                                                      B0000600
      U(I)=U(I+1)                                                    B0000610
      I=1+NXM1*NY                                                    B0000620
      U(I)=U(I+1)                                                    B0000630
C---------------------------------  UPDATE H AT EXIT                 B0000640
      IF(IX.NE.2) RETURN                                             B0000650
      IF(IBC.EQ.1) RETURN                                            B0000660
      DO 42 IY=1YW,NY                                                B0000670
      I=IY+IX1NY                                                     B0000680
      IW=I-NY                                                        B0000690
   42 H(IW)=H(I)                                                     B0000700
      RETURN                                                         B0000710
C                                                                    B0000720
C-----UPDATE MIXTURE FRACTION ON BOUNDARIES.                         B0000730
C-----AT PIPE WALL.                                                  B0000740
   50 I=NY+IX1NY                                                     B0000750
      FM(I)=FM(I-1)                                                  B0000760
C-----AT PIPE AXIS.                                                  B0000770
      I=1+IX1NY                                                      B0000780
      FM(I)=FM(I+1)                                                  B0000790
C-----SET MIXTURE FRACTION AT NODES IN THE INNER WALL TO ZERO.       B0000800
      IF(IX.GT.IXW) GO TO 51                                         B0000810
      I=IYW+IX1NY                                                    B0000820
      FM(I)=0.0                                                      B0000830
C-----AT PIPE EXIT.                                                  B0000840
   51 IF (IX.NE.2) GO TO 53                                          B0000850
      IF(IBC.EQ.1) GO TO 53                                          B0000860
      DO 52 IY=IYWP1,NY                                              B0000870
      I=IY+IX1NY                                                     B0000880
      IW=I-NY                                                        B0000890
   52 FM(IW)=FM(I)                                                   B0000900
   53 IF(IX.NE.NXM1) RETURN                                          B0000910
      DO 54 IY=1,NY                                                  B0000920
      I=IY+IX1NY                                                     B0000930
      IE=I+NY                                                        B0000940
   54 FM(IE)=FM(I)                                                   B0000950
      RETURN                                                         B0000960
C                                                                    B0000970
C-----UPDATE FUEL MASS FRACTION ON BOUNDARIES.                       B0000980
C-----AT PIPE WALL.                                                  B0000990
   60 I=NY+IX1NY                                                     B0001000
      FUE(I)=FUE(I-1)                                                B0001010
C-----AT PIPE AXIS.                                                  B0001020
      I=1+IX1NY                                                      B0001030
      FUE(I)=FUE(I+1)                                                B0001040
```

```
C-----SET FUEL MASS FRACTION AT NODES IN THE INNER WALL TO ZERO.          B0001050
      IF(IX.GT.IXM) GO TO 610                                            B0001060
      I=IYW+IX1NY                                                        B0001070
      FUE(I)=0.0                                                         B0001080
C-----AT PIPE EXIT.                                                      B0001090
  610 IF (IX.NE.2) GO TO 630                                             B0001100
      IF(INC.EQ.1) GO TO 630                                             B0001110
      DO 620 IY=IYWP1,NY                                                 B0001120
      I=IY+IX1NY                                                         B0001130
      IW=I-NY                                                            B0001140
  620 FUE(IW)=FUE(I)                                                     B0001150
  630 IF(IX.NE.NX-1) GO TO 650                                           B0001160
      DO 640 IY=1,NY                                                     B0001170
      I=IY+IX1NY                                                         B0001180
      IE=I+NY                                                            B0001190
  640 FUE(IE)=FUE(I)                                                     B0001200
C                                                                        B0001210
C-----UPDATE SPECIES MASS FRACTIONS ON BOUNDARIES.                       B0001220
C                                                                        B0001230
  650 I1=1+IX1NY                                                         B0001240
      INY=NY+IX1NY                                                       B0001250
      DO 61 J=JS1,JS2                                                    B0001260
C-----AT PIPE WALL.                                                      B0001270
      IF=INY+IZERO(J)                                                    B0001280
      F(IF)=F(IF-1)                                                      B0001290
C-----AT PIPE AXIS.                                                      B0001300
      I1=I1+IZERO(J)                                                     B0001310
   61 F(I1)=F(I1+1)                                                      B0001320
C-----SET SPECIES MASS FRACTIONS AT NODES IN THE INNER WALL TO ZERO.     B0001330
      IF(IX.GT.IXM) GO TO 66                                             B0001340
      I=IYW+IX1NY                                                        B0001350
      DO 62 J=JS1,JS2                                                    B0001360
      IF=I+IZERO(J)                                                      B0001370
   62 F(IF)=0.0                                                          B0001380
C-----AT PIPE EXIT.                                                      B0001390
   66 IF(IX.NE.2) GO TO 64                                               B0001400
      IF(INC.EQ.1) GO TO 64                                              B0001410
      DO 63 IY=IYWP1,NY                                                  B0001420
      I=IY+IX1NY                                                         B0001430
      DO 63 J=JS1,JS2                                                    B0001440
      IF=I+IZERO(J)                                                      B0001450
      IFW=IF-NY                                                          B0001460
   63 F(IFW)=F(IF)                                                       B0001470
   64 IF(IX.NE.NXM1) RETURN                                              B0001480
C-----AT PIPE WALL.                                                      B0001490
      DO 65 IY=1,NY                                                      B0001500
      I=IY+IX1NY                                                         B0001510
      DO 65 J=JS1,JS2                                                    B0001520
      IF=I+IZERO(J)                                                      B0001530
      IFE=IF+NY                                                          B0001540
   65 F(IFE)=F(IF)                                                       B0001550
      RETURN                                                             B0001560
```

```
C                                                                       B0001570
C-----UPDATE TEMPERATURE ON BOUNDARIES.                                 B0001580
C-----AT PIPE AXIS.                                                     B0001590
  110 I=1+IX1NY                                                         B0001600
      TEM(I)=TEM(I+1)                                                   B0001610
      I=1+NXM1*NY                                                       B0001620
      TEM(I)=TEM(I+1)                                                   B0001630
C-----AT PIPE EXIT.                                                     B0001640
      IF (IX.NE.2) RETURN                                               B0001650
      IF(INC.EQ.1) RETURN                                               B0001660
      DO 112 IY=IYW,NY                                                  B0001670
      I=IY+IX1NY                                                        B0001680
      IW=I-NY                                                           B0001690
  112 TEM(IW)=TEM(I)                                                    B0001700
      RETURN                                                            B0001710
C                                                                       B0001720
C-----SET PRESSURE AT NODES IN THE INNER WALL TO ZERO.                  B0001730
C                                                                       B0001740
  120 IF (IX.GT.IXW) RETURN                                             B0001750
      I=IYWM1+IX2NY2                                                    B0001760
      P(I)=0.0                                                          B0001770
      RETURN                                                            B0001780
C                                                                       B0001790
C-----UPDATE DENSITY ON BOUNDARIES.                                     B0001800
C-----AT PIPE WALL.                                                     B0001810
  130 I=NY+IX1NY                                                        B0001820
      RHO(I)=RHO(I-1)                                                   B0001830
C-----AT PIPE AXIS.                                                     B0001840
      I=1+IX1NY                                                         B0001850
      RHO(I)=RHO(I+1)                                                   B0001860
C-----AT PIPE EXIT.                                                     B0001870
      IF (IX.NE.2) RETURN                                               B0001880
      IF(INC.EQ.1) RETURN                                               B0001890
      DO 132 IY=IYWP1,NY                                                B0001900
      I=IY+IX1NY                                                        B0001910
      IW=I-NY                                                           B0001920
  132 RHO(IW)=RHO(I)                                                    B0001930
      RETURN                                                            B0001940
C                                                                       B0001950
C-----UPDATE VISCOSITY ON BOUNDARIES.                                   B0001960
C                                                                       B0001970
C-----AT PIPE WALL.                                                     B0001980
  140 I=NY+IX1NY                                                        B0001990
      EMU(I)=EMU(I-1)                                                   B0002000
C-----AT PIPE AXIS.                                                     B0002010
      I=1+IX1NY                                                         B0002020
      EMU(I)=EMU(I+1)                                                   B0002030
C-----AT PIPE EXIT.                                                     B0002040
      IF (IX.NE.2) GO TO 141                                            B0002050
      IF(INC.EQ.1) GO TO 141                                            B0002060
      DO 143 IY=IYWP1,NY                                                B0002070
      I=IY+IX1NY                                                        B0002080
```

```
      IX=I-IY                                                          B0002090
  145 EXU(IW)=EXU(I)                                                   B0002100
  141 IF (IX.NE.NXM1) RETURN                                           B0002110
      DO 142 IY=1,NY                                                   B0002120
      I=IY+IX*NY                                                       B0002130
      IW=1+NY                                                          B0002140
  142 EXU(IE)=EXU(I)                                                   B0002150
      RETURN                                                           B0002160
      END                                                              B0002170
```

```
                                                                        S0000010
      SUBROUTINE SOURCE(LPHI)                                           S0000020
C-----------------------------------------------------------------------S0000030
CHAPTER  0  0  0  0  0  0  0  0     DECLARATIONS  0  0  0  0  0  0  0  0  S0000040
C-----------------------------------------------------------------------S0000050
      COMMON/C01A/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),     S0000060
     1 FP(20),TEM(500),P(414),RHO(500),EMU(500),                        S0000070
     1 DXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),   S0000080
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                          S0000090
     3 A(20),AE(20),AN(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),     S0000100
     4 BSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),           S0000110
     5 DIFNP(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),      S0000120
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),       S0000130
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),    S0000140
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),           S0000150
     9 AIDDY(500),AREAN(500),VOL(500),                                  S0000160
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),             S0000170
     1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),        S0000180
     2 RSREF(25),RSSUM(25),TITLE(25)                                    S0000190
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)      S0000200
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),          S0000210
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))               S0000220
      COMMON/COMP/                                                      S0000230
     1 AK,ARRLOW,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,     S0000240
     2 EPSI,ERRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,          S0000250
     3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,        S0000260
     4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,          S0000270
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,     S0000280
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,       S0000290
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,     S0000300
     8 LABPHI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,     S0000310
     9 NXM2,NXY,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,         S0000320
     X PRLXP,PRESS,RELAXP,RF,RFSTM,RSCHEK,RSMAX,R1I,R1O,R2I,R2O,        S0000330
     1 STOICH,T3,TC,TINY,TMAX,TMIN,UB,UC,WMIX                           S0000340
      LOGICAL CONVG                                                     S0000350
      COMMON /INDEX/ IDCO,IDCO2,IDF,IDH,IDH2,IDH20,IDO,IDOH,IDO2,IDN,   S0000360
     1 IDHO,IDN2,IDN2,IDN20,IEQUIL,IHCPS,IPR,JJ,KNTCS,NA,NLM,           S0000370
     2 NS,NSE1,NSE2,NSK,NSM,NS1,NS2,ID(4,15)                            S0000380
     3/PARAMS/ CONVG,EMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNYS0000390
     5/SPECIES/ASUB(20,3),CPSUM,HSUM,HO(14),SMW(14),SO(14),S1(14),      S0000400
     6 S2(14),Z(2,7,14)                                                 S0000410
     7/GEOM1L/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,      S0000420
     8 AS1(4,7,2),HDIV,HMAX,HMIN,PEXP(7)                               S0000430
     9/REACTS/BX(15),BX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)        S0000440
      COMMON/OTH/ ALNR1I,ALNR1O,ALNR2I,ALNR2O,COND,EL3,                 S0000450
     1 EMIS1O,EMIS2I,EMIS2O,EMISXI,EMISXO,REMI,RHOINF,                  S0000460
     1 SIGMA,STV1,STXG,ST1I,ST1O,ST2I,ST2O,TINF,UINF,VINF,WAREA         S0000470
C-----------------------------------------------------------------------S0000480
CHAPTER 1  1  1  1  1  1  1    PRELIMINARIES  1  1  1  1  1  1  1  1  1 S0000490
C-----------------------------------------------------------------------S0000500
      DATA SHALL/0.04/                                                  S0000510
      JPHI=LPHI                                                         S0000520
```

```
      IF (JPHI.EQ.JU)   GO TO 10                                          S0000530
      IF (JPHI.EQ.JV)   GO TO 20                                          S0000540
      IF (JPHI.EQ.JH)   GO TO 40                                          S0000550
      IF (JPHI.EQ.JEN)  GO TO 50                                          S0000560
      IF (JPHI.EQ.JEDF) GO TO 60                                          S0000570
      IF (JPHI.EQ.JPP)  GO TO 90                                          S0000580
      RETURN                                                              S0000590
C-----------------------------------------------------------------------S0000600
CHAPTER 2  2  2  2  2  2   SOURCE TERMS FOR U   2  2  2  2  2  2  2  2  S0000610
C-----------------------------------------------------------------------S0000620
   10 ICONST=IX*NYU-1                                                     S0000630
      IF (ARHOMU.EQ.0) GO TO 12                                           S0000640
      RHOXU1X=RDXU(IXU)                                                   S0000650
      RHOXU1=RDXU(IXUP1)                                                  S0000660
      RSXU1X=RSXU(IXU)                                                    S0000670
      QRDX=0.25*RDXU(IXUP1)                                               S0000680
C                                                                         S0000690
      I=IYFM1+IX1UNYU                                                     S0000700
      IE=I+NY                                                             S0000710
      IN=I+1                                                              S0000720
      INE=IN+NY                                                           S0000730
      IXU1NY=(IXU-1)*NYM1                                                 S0000740
      IV=IYFM1+IXU1NY                                                     S0000750
      IEV=IV+NY+1                                                         S0000760
      EDVDXN=(EMU(I)+EMU(IE)+EMU(IN)+EMU(INE))*(V(IEV)-V(IV))*RV(IYFM1)   S0000770
      DO 11 IY=1YF,1YL                                                    S0000780
      I=IY+IX1NYU                                                         S0000790
      IE=I+NY                                                             S0000800
      IW=I-NY                                                             S0000810
      IN=I+1                                                              S0000820
      INE=IN+NY                                                           S0000830
      IV=IY+IXU1NY                                                        S0000840
      IEV=IV+NY+1                                                         S0000850
      IEP=IY+ICONST                                                       S0000860
      IECP=IEP+NY+2                                                       S0000870
      DUDXW=(U(I)-U(IW))*RDXU1X                                           S0000880
      DUDXE=(U(IE)-U(I))*RDXU11                                           S0000890
      STERM=(EMU(IE)*DUDXE-EMU(IW)*DUDXW)*RSXU1X                          S0000900
      EDVDXS=EDVDXN                                                       S0000910
      EDVDXN=(EMU(I)+EMU(IE)+EMU(IN)+EMU(INE))*(V(IEV)-V(IV))*RV(IY)      S0000920
      STERM=STERM+(EDVDXN-EDVDXS)*RRDXG/AREAF(IY)                         S0000930
      SU(IY)=AREAC(IY)*(P(IP)-P(IECP))+0.5*STERM*(VOL(I)+VOL(IE))         S0000940
      SV(IY)=0.0                                                          S0000950
C------------ INERTIAL UNDER-RELAXATION ------------------------------- S0000960
      AFAC=1.                                                             S0000970
      ASU=AFAC*ABS(SU(IY))                                                S0000980
      AFACT=ASU/(ABS(U(I))+TINY)                                          S0000990
      AFAT=1.E3*ASU                                                       S0001000
      AFACT=AMIN1(AFACT,AFAT)                                             S0001010
      SU(IY)=SU(IY)+AFACT*U(I)                                            S0001020
      SP(IY)=SP(IY)-AFACT                                                 S0001030
   11 CONTINUE                                                            S0001040
```

```
      GO TO 19                                                          S0001050
   12 DO 13 IY=IYF,IYL                                                  S0001060
      IP=IY+ICONST                                                      S0001070
      ILP=IP+IY-2                                                       S0001080
      SU(IY)=AREA(IY)*(P(IP)-P(ILP))                                    S0001090
   13 SP(IY)=0.0                                                        S0001100
C                                                                       S0001110
   14 IF(IYU.EQ.IXW.AND.INC.EQ.-1) GO TO 1000                           S0001120
      GO TO 1002                                                        S0001130
 1000 DO 1001 IY=2,IYW                                                  S0001140
      I=IY+IX1NYU                                                       S0001150
      SU(IY)=RHO*U(I)                                                   S0001160
 1001 SP(IY)=-BIG                                                       S0001170
C-----EXTRA SOURCES DUE TO INNER TUBE.                                  S0001180
 1002 IF (IXU.GT.IXW) RETURN                                            S0001190
      IF (INC.NE.1) GO TO 15                                            S0001200
      IP=IYWM1                                                          S0001210
      I3=IYW                                                            S0001220
      GO TO 16                                                          S0001230
   15 I2=IYWP1                                                          S0001240
      I3=IYWP1                                                          S0001250
   16 I=I2+IX1NYU                                                       S0001260
      RUREF=RHO(1)*ABS(U(I))                                            S0001270
      RE=0.5*RUREF*DYG(I3)/EMUREF                                       S0001280
      IF (KLT.EQ.1) GO TO 19                                            S0001290
      IF (RE.LT.132.25) GO TO 19                                        S0001300
      ER=RE*EWALL                                                       S0001310
      ARGMIN=11.5*EWALL                                                 S0001320
      DO 17 NIT=1,11                                                    S0001330
      SHALF1=SHALF                                                      S0001340
      ARG=ER*SHALF                                                      S0001350
      IF (ARG.LT.ARGMIN) GO TO 19                                       S0001360
      SHALF=AK/ALOG(ARG)                                                S0001370
      IF (ABS(SHALF-SHALF1).LT.0.0001) GO TO 18                         S0001380
   17 CONTINUE                                                          S0001390
   18 S=SHALF**2                                                        S0001400
      SP(I2)=SP(I2)-S*R(I2)*RUREF*SXU(IXU)                              S0001410
      RETURN                                                            S0001420
   19 SP(I2)=SP(I2)-EMUREF*SXU(IXU)*R(I2)/(DYG(I3)*0.5)                 S0001430
      RETURN                                                            S0001440
C-----------------------------------------------------------------------S0001450
CHAPTER 3  3  3  3  3  3   SOURCE TERMS FOR V  3  3  3  3  3  3  3  3  S0001460
C-----------------------------------------------------------------------S0001470
   20 ICONST=IX2NY2-1                                                   S0001480
      IF (IX.EQ.2.AND.INC.EQ.-1) GO TO 25                               S0001490
      IF (KRHOM1.EQ.0) GO TO 22                                         S0001500
      QRSXG=0.25*RSXG(IX)                                               S0001510
      IL=IYF+IX1NY                                                      S0001520
      IV=IYFM1+IX1NY1                                                   S0001530
      EMVDT=EMU(IV)*(V(IV+1)-V(IV))*RDYV(IYF)*R(IYF)                    S0001540
      DO 21 IY=IYF,IYLM1                                                S0001550
      IYP1=IY+1                                                         S0001560
```

```
      I=IY+1X1NY                                                          S0001570
      IE=I+1                                                              S0001580
      IF=I+IY                                                             S0001590
      INE=IE+1                                                            S0001600
      IW=I-IY                                                             S0001610
      INW=IW+1                                                            S0001620
      IV=IY+1X1NY1                                                        S0001630
      IF=IY+ICONST                                                        S0001640
      EMUM=EMU(I)+EMU(IN)                                                 S0001650
      EMUE=EMUM+EMU(IF)+EMU(INE)                                          S0001660
      EMUW=EMUM+EMU(IW)+EMU(INW)                                          S0001670
      STERM=(EMUE*(U(IN)-U(I))-EMUW*(U(INW)-U(IW)))*QRSXG*RDYG(IYP1)      S0001680
      EDVDYS=EDVDYN                                                       S0001690
      EDVDYN=EMU(IN)*(V(IV+1)-V(IV))*RDYV(IYP1)*R(IYP1)                   S0001700
      STERM=STERM+(EDVDYN-EDVDYS)/AREAE(IY)                               S0001710
      VOLUME=0.5*(VOL(I)+VOL(IN))                                         S0001720
      SU(IY)=STERM*VOLUME+AREAN(I)*(P(IP)-P(IP+1))                        S0001730
      SP(IY)=-EMUM*VOLUME/RVSQ(IY)                                        S0001740
C------------ INERTIAL UNDER-RELAXATION ------------------------------   S0001750
      AFAC=0.0                                                            S0001760
      ASU=AFAC*ABS(SU(IY))                                                S0001770
      AFACT=ASU/(ABS(V(IV))+TINY)                                         S0001780
      AFAT=1.5E3*ASU                                                      S0001790
      AFACT=AMIN1(AFACT,AFAT)                                             S0001800
      SU(IY)=SU(IY)+AFACT*V(IV)                                           S0001810
      SP(IY)=SP(IY)-AFACT                                                 S0001820
   21 CONTINUE                                                            S0001830
      RETURN                                                              S0001840
   22 DO 23 IY=IYF,IYLM1                                                  S0001850
      I=IY+1X1NY                                                          S0001860
      IN=I+1                                                              S0001870
      IF=IY+ICONST                                                        S0001880
      SU(IY)=AREAN(I)*(P(IP)-P(IP+1))                                     S0001890
   23 SP(IY)=-.25*(EMU(I)+EMU(IN))*(VOL(I)+VOL(IN))/RVSQ(IY)              S0001900
      RETURN                                                              S0001910
   25 DO 26 IY=IYF,IYLM1                                                  S0001920
      SU(IY)=0.0                                                          S0001930
   26 SP(IY)=-BIG                                                         S0001940
      RETURN                                                              S0001950
C-------------------------------------------------------------------------S0001960
CHAPTER 4  4  4  4  4  4  4   SOURCE TERMS FOR H  4  4  4  4  4  4  4  4  S0001970
C-------------------------------------------------------------------------S0001980
   40 CONTINUE                                                            S0001990
      DO 460 IY=IYF,IYL                                                   S0002000
      SU(IY)=0.0                                                          S0002010
  460 SP(IY)=0.0                                                          S0002020
C                                                                         S0002030
      IF(IX.EQ.NX) GO TO 430                                              S0002040
      I=IYM+1X1NY                                                         S0002050
      IS=I-1                                                              S0002060
      IN=I+1                                                              S0002070
      IE=I+IY                                                             S0002080
```

```
      IS=I-NY                                                          S0002090
      ISW=IS-1                                                         S0002100
      ISE=IS+1                                                         S0002110
      IWALS=NY+IX1-NY                                                  S0002120
      IWALSW=IWALS-1                                                   S0002130
      IWALL=IWALS+NY                                                   S0002140
      IWALW=IWALS-NY                                                   S0002150
      IWALSW=IWALW-1                                                   S0002160
C                                                                      S0002170
      QRADI3=0.0                                                       S0002180
      QRADI4=0.0                                                       S0002190
      IF (IX.GT.IXW) GO TO 415                                         S0002200
      AE(IYW)=0.0                                                      S0002210
      AN(IYW)=0.0                                                      S0002220
      AS(IYW)=0.0                                                      S0002230
      AW(IYW)=0.0                                                      S0002240
      AS(IYWP1)=0.0                                                    S0002250
      AN(IYWM1)=0.0                                                    S0002260
      H1I=ST1I*RHO(IS)*ABS(0.5*(U(IS)+U(ISW)))*CMIX                    S0002270
      RU1I=SXG(IX)/(1.0/(R1I*H1I)+ALNR1I/COND)                         S0002280
      Q1I=RU1I*TEM(IS)                                                 S0002290
      H1O=ST1O*RHO(IN)*ABS(0.5*(U(IN)+U(INW)))*CMIX                    S0002300
      RU1O=SXG(IX)/(1.0/(R1O*H1O)+ALNR1O/COND)                         S0002310
      Q1O=RU1O*TEM(IN)                                                 S0002320
      IF (IX.EQ.2) GO TO 401                                           S0002330
      IF (IX.EQ.IXW) GO TO 405                                         S0002340
      CAREA=COND*AREAE(IYW)                                            S0002350
      GAMAE=CAREA*RDXG(IXP1)                                           S0002360
      GAMAW=CAREA*RDXG(IX)                                             S0002370
      QCOND1=GAMAE+GAMAW                                               S0002380
      QCOND2=GAMAE*TEM(IE)+GAMAW*TEM(IW)                               S0002390
      GO TO 410                                                        S0002400
  401 GAMAE=COND*AREAE(IYW)*RDXG(IXP1)                                 S0002410
      QCOND1=GAMAE                                                     S0002420
      QCOND2=GAMAE*TEM(IE)                                             S0002430
      GO TO 410                                                        S0002440
  405 GAMAW=COND*AREAE(IYW)*RDXG(IX)                                   S0002450
      QCOND1=GAMAW                                                     S0002460
      QCOND2=GAMAW*TEM(IW)                                             S0002470
  410 CONTINUE                                                         S0002480
      QRADI1=SIGMA*(TEM(IWAL)+TEM(I))*(TEM(IWAL)**2+TEM(I)**2)         S0002490
     1 /(1.0/(AREAN(I)*EMIS1O)+REMI/AREAN(IWALS))                      S0002500
      QRADI3=QRADI1                                                    S0002510
      QRADI4=QRADI1*TEM(I)                                             S0002520
      SU(IYWM1)=RU1I*TEM(I)-Q1I                                        S0002530
      SU(IYW)=QCOND2+QRADI1*TEM(IWAL)+Q1I+Q1O                          S0002540
      SP(IYW)=-QCOND1-QRADI1-RU1I-RU1O                                 S0002550
      SU(IYWP1)=RU1O*TEM(I)-Q1O                                        S0002560
  415 H2I=ST2I*RHO(IWALS)*ABS(0.5*(U(IWALS)+U(IWALSW)))*CMIX           S0002570
      RU2I=SXG(IX)/(1.0/(R2I*H2I)+ALNR2I/COND)                         S0002580
      Q2I=RU2I*TEM(IWALS)                                              S0002590
      H2O=ST2O*RHOINF*ABS(UINF)*CMIX                                   S0002600
```

```
      RU2O=SXG(IX)/(1.0/(R2O*H2O)+ALHR2O/COND)                          S0002610
      Q2O=RU2O*TIN                                                      S0002620
      IF(IX.EQ.2) GO TO 416                                             S0002630
      CAREA=COND*WAREA                                                  S0002640
      GAMAE=CAREA*RDXG(IXP1)                                            S0002650
      GAMAW=CAREA*RDXG(IX)                                              S0002660
      QCOND1=GAMAE+GAMAW                                                S0002670
      QCOND2=GAMAE*TEM(IWALE)+GAMAW*TEM(IWALW)                          S0002680
      GO TO 420                                                         S0002690
  416 GAMAE=COND*WAREA*RDXG(IXP1)                                       S0002700
      QCOND1=GAMAE                                                      S0002710
      QCOND2=GAMAE*TEM(IE)                                              S0002720
  420 QRAD01=SIGMA*SXG(IX)*R2O*EMIS2O*(TINF+TEM(IWAL))                  S0002730
     1 *(TINF**2+TEM(IWAL)**2)                                          S0002740
      SU(NY)=QCOND2+QRAD14+QRAD01*TINF+Q2I+Q2O                          S0002750
      SP(NY)=-QCOND1-QRAD13-QRAD01-RU2I-RU2O                            S0002760
      SU(NYM1)=RU2I*TEM(IWAL)-Q2I                                       S0002770
C                                                                       S0002780
      IF(IX.NE.IXM1) RETURN                                             S0002790
      HEL3C=0.5*EL3/COND                                                S0002800
      DO 425 IY=2,NYM1                                                  S0002810
      I=IY+IX1NY                                                        S0002820
      IE=I+NY                                                           S0002830
      IV=IY+IX1NY1                                                      S0002840
      IVS=IV-1                                                          S0002850
      HXI=STXI*RHO(I)*ABS(0.5*(V(IV)+V(IVS)))*CMIX                      S0002860
      UXI=AREAE(IY)/(1.0/HXI+HEL3C)                                     S0002870
      QXI=UXI*(TEM(I)-TEM(IE))                                          S0002880
  425 SU(IY)=SU(IY)-QXI                                                 S0002890
      RETURN                                                            S0002900
  430 DO 435 IY=IYF,IYL                                                 S0002910
      I=IY+IX1NY                                                        S0002920
      IV=IY+IX1NY1                                                      S0002930
      IW=I-NY                                                           S0002940
      IVW=IV-NYM1                                                       S0002950
      IVSW=IVW-1                                                        S0002960
      IN=I+1                                                            S0002970
      IS=I-1                                                            S0002980
      CONDL=COND*EL3                                                    S0002990
      IF(IY.EQ.NY) GO TO 431                                            S0003000
      HXI=STXI*RHO(IW)*ABS(0.5*(V(IVW)+V(IVSW)))*CMIX                   S0003010
      UXI=AREAE(IY)/(1.0/HXI+HEL3C)                                     S0003020
      QXI=UXI*TEM(IW)                                                   S0003030
      GAMAW=CONDL/ALOG(R(IY+1)/R(IY))                                   S0003040
      GO TO 432                                                         S0003050
  431 UXI=0.0                                                           S0003060
      QXI=0.0                                                           S0003070
      GAMAW=0.0                                                         S0003080
      HXO=STXO*RHOINF*ABS(VINF)*CMIX                                    S0003090
      UXO=WAREA/(1.0/HXO+HEL3C)                                         S0003100
      GO TO 436                                                         S0003110
  432 HXO=STXO*RHOINF*ABS(VINF)*CMIX                                    S0003120
```

```
      UXO=AREAE(IY)/(1.0/HXO+HEL3G)                                    S0003130
  436 QXO=UXO*TINF                                                     S0003140
      IF(IY.EQ.2) GO TO 433                                            S0003150
      GAMAS=COND1/ALOG(R(IY)/R(IY-1))                                  S0003160
      GO TO 434                                                        S0003170
  433 GAMAS=0.0                                                        S0003180
  434 AN(IY)=GAMAN                                                     S0003190
      AS(IY)=GAMAS                                                     S0003200
      QRAD1=SIGMA*AREAE(IY)*(EMISXI+EMISXO)*(TINF+TEM(I))              S0003210
     1 *(TINF**2+TEM(I)**2)                                            S0003220
      AW(IY)=0.0                                                       S0003230
      SU(IY)=QRAD1*TINF+QXI+QXO                                        S0003240
  435 SP(IY)=-QRAD1-UXI-UXO                                            S0003250
      GAMAW=COND*WAREA*RDXG(IX)                                        S0003260
      SU(NY)=SU(NY)+GAMAW*TEM(IX1NY)                                   S0003270
      SP(NY)=SP(NY)-GAMAW                                              S0003280
      H2O=ST2O*RHOINF*ABS(UINF)*CMIX                                   S0003290
      RU2O=EL3/(1.0/(R2O*H2O)+ALNR2O/COND)                             S0003300
      Q2O=RU2O*TINF                                                    S0003310
      SU(NY)=SU(NY)+Q2O                                                S0003320
      SP(NY)=SP(NY)-RU2O                                               S0003330
      RETURN                                                           S0003340
C-----------------------------------------------------------------------S0003350
CHAPTER  5  5  5  5  5  SOURCE TERMS FOR MIXTURE FRACTION  5  5  5  5  5S0003360
C-----------------------------------------------------------------------S0003370
   50 DO 52 IY=IYF,IYL                                                 S0003380
      SU(IY)=0.0                                                       S0003390
   52 SP(IY)=0.0                                                       S0003400
      RETURN                                                           S0003410
C-----------------------------------------------------------------------S0003420
CHAPTER  6  6  6  6  6  6  6  SOURCE TERMS FOR FUEL  6  6  6  6  6  6  6S0003430
C-----------------------------------------------------------------------S0003440
   60 T1=PRECXP*PRESS**2                                               S0003450
      DO 62 IY=IYF,IYL                                                 S0003460
      I=IY+IX1NY                                                       S0003470
      FUBRNT=AMAX1(0.0,(FM(I)-FSTOIC)*RFSTM)                           S0003480
      FUEX=FUE(I)-FUBRNT                                               S0003490
      IF (FUEX.GT.0.0) GO TO 61                                        S0003500
      SP(IY)=-BIG                                                      S0003510
      GO TO 62                                                         S0003520
   61 FOX=AMAX1(TINY,STOICH*(FUE(I)-(FM(I)-FSTOIC)*RFSTM))             S0003530
      SP(IY)=-T1*EXP(-ARRCON/TEM(I))*VOL(I)*FOX*FUE(I)/FUEX            S0003540
   62 SU(IY)=-SP(IY)*FUBRNT                                            S0003550
      RETURN                                                           S0003560
C-----------------------------------------------------------------------S0003570
CHAPTER 7  7  7  7  7  7   SOURCE TERMS FOR P'  7  7  7  7  7  7  7  7  S0003580
C-----------------------------------------------------------------------S0003590
   90 ERROR=0.0                                                        S0003600
      IF (IX.EQ.2.AND.INC.EQ.-1) GO TO 93                              S0003610
      DO 92 IY=IYF,IYL                                                 S0003620
C     ERROR MASS SOURCES                                               S0003630
      ESMASS=-FLOWN(IY)+FLOWN(IY-1)-FLOWE(IY)+FLOWW(IY)                S0003640
```

```
      SU(IY)=ESMASS                                                    S0003650
      SP(IY)=0.0                                                       S0003660
   92 ERROR=ERROR+ABS(ESMASS)                                          S0003670
      IF (IX.NE.NXM1.OR.INC.NE.1) GO TO 95                             S0003680
      SU(IYL)=0.0                                                      S0003690
      SP(IYL)=-BIG                                                     S0003700
      GO TO 95                                                         S0003710
C-----OUTLET BOUNDARY - UNIFORM PRESSURE ASSUMED.                      S0003720
   93 DO 94 IY=IYF,IYL                                                 S0003730
      SU(IY)=0.0                                                       S0003740
   94 SP(IY)=-BIG                                                      S0003750
   95 RSLINE(IX,JPP)=ERROR/RSREF(JPP)                                  S0003760
      ARSL(IX,JPP)=ABS(RSLINE(IX,JPP))                                 S0003770
      RETURN                                                           S0003780
      END                                                              S0003790
```

```
      SUBROUTINE WALL(I1,STERM,STERM1,IY,JPHI)                          WA000010
      COMMON/COMA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),    WA000020
     1 FP(20),TFM(500),P(414),RHO(500),EMU(500),                        WA000030
     1 FAG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),   WA000040
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                          WA000050
     3 A(20),AE(20),AH(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),     WA000060
     4 BSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),           WA000070
     5 DIFNN(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),      WA000080
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),      WA000090
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),    WA000100
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),           WA000110
     9 ANDDY(500),AREAN(500),VOL(500),                                  WA000120
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),             WA000130
     1 ICW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),        WA000140
     2 LSREF(25),RSSUM(25),TITLE(25)                                    WA000150
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)      WA000160
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),          WA000170
     1 FLOWFE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))               WA000180
      COMMON/COMB/                                                      WA000190
     1 AK,ARROW,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,      WA000200
     2 EPST,ERAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,           WA000210
     3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,        WA000220
     4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,          WA000230
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,     WA000240
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,       WA000250
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,     WA000260
     8 LABPHI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,     WA000270
     9 NXM2,NYYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,       WA000280
     X PRELXP,PRLSS,RELAXP,RF,RFSTM,RSCHEK,RSMAX,R1I,R1O,R2I,R2O,       WA000290
     1 STOICH,TB,TC,TINY,TMAX,TMIN,UB,UC,WMIX                          WA000300
      DATA SHALF/0.04/                                                  WA000310
      KWALL=2-1/11                                                      WA000320
      I2=I1+3-2*KWALL                                                   WA000330
      I3=I1+2-KWALL                                                     WA000340
      IF (IY.NE.0) GO TO 10000                                          WA000350
      I=I2+IX1NY                                                        WA000360
      IF (JPHI.EQ.JU)   GO TO 10                                        WA000370
      RETURN                                                            WA000380
C                                                                       WA000390
   10 I=I2+IX1NYU                                                       WA000400
      RUREF=RHO(I)*ABS(U(I))                                            WA000410
      RL=RUREF*DYG(I3)/EMUREF                                           WA000420
      IF(RLT.EQ.1) GO TO 19                                             WA000430
      IF (RL.LT.132.25) GO TO 19                                        WA000440
      ER=RF*EWALL                                                       WA000450
      ARGMIN=11.5*EWALL                                                 WA000460
      DO 17 NIT=1,11                                                    WA000470
      SHALF1=SHALF                                                      WA000480
      ARG=ER*SHALF                                                      WA000490
      IF (ARG.LT.ARGMIN) GO TO 19                                       WA000500
      SHALF=AK/ALOG(ARG)                                                WA000510
                                                                        WA000520
```

```
      IF (ABS(SHALF-SHALF1).LT.0.0001) GO TO 18                          WA000530
   17 CONTINUE                                                           WA000540
   18 S=SHALF**2                                                         WA000550
      STERM1=S*R(I2)*RUREF*SXU(IXU)                                      WA000560
      RETURN                                                             WA000570
   19 STERM1=EMUREF*SXU(IXU)*R(I1)*RDYG(I3)                              WA000580
      RETURN                                                             WA000590
10000 I=IY+IXIMY                                                         WA000600
      IF (JPHI.EQ.JV)   GO TO 200                                        WA000610
      RETURN                                                             WA000620
  200 RUREF=RHO(I)*ABS(V(I))                                             WA000630
      RE=RUREF*DYG(I3)/EMUREF                                            WA000640
      IF(RE.LT.0.1) GO TO 290                                            WA000650
      IF (RE.LT.132.25) GO TO 290                                        WA000660
      EL=RE*EWALL                                                        WA000670
      ARGMIN=11.5*EWALL                                                  WA000680
      DO 270 II1=1,11                                                    WA000690
      SHALF1=SHALF                                                       WA000700
      ARG=EL*SHALF                                                       WA000710
      IF (ARG.LT.ARGMIN) GO TO 290                                       WA000720
      SHALF=AL/ALOG(ARG)                                                 WA000730
      IF (ABS(SHALF-SHALF1).LT.0.0001) GO TO 280                         WA000740
  270 CONTINUE                                                           WA000750
  280 S=SHALF**2                                                         WA000760
      STERM1=S*RUREF*SYV(IY)*RV(IY)                                      WA000770
      RETURN                                                             WA000780
  290 STERM1=EMUREF*SYV(IY)*RV(IY)*RDXG(I3)                              WA000790
      RETURN                                                             WA000800
      END                                                                WA000810
```

```
                                                                        CH000010
      SUBROUTINE  CHEM(KGOTO)                                           CH000020
      COMMON/COMA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),    CH000030
     1 PP(20),TFM(500),P(414),RHO(500),EMU(500),                        CH000040
     1 DXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),   CH000050
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                          CH000060
     3 A(24),F(20),AN(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),      CH000070
     4 DSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),           CH000080
     5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),      CH000090
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),       CH000100
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),    CH000110
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),           CH000120
     9 ANDDY(500),AREAN(500),VOL(500),                                  CH000130
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),             CH000140
     1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),        CH000150
     2 RSREF(25),RSSUM(25),TITLE(25)                                    CH000160
      DIMENSION DIFNW(20),DIFSW(20),F(11889),FLOWNW(20),FLOWWW(20)      CH000170
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),          CH000180
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))               CH000190
      COMMON/COMB/                                                      CH000200
     1 AK,APRCON,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,     CH000210
     2 EPSI,EGRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,          CH000220
     3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,        CH000230
     4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,          CH000240
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,     CH000250
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,       CH000260
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,     CH000270
     8 LABPHI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,     CH000280
     9 NXM2,NYYU,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,        CH000290
     X PREXP,PRESS,RELAXP,RF,RFSTM,RSCHEK,RSMAX,R1I,R1O,R2I,R2O,        CH000300
     1 STOICH,TB,TC,TINY,TMAX,TMIN,UB,UC,WM1X                           CH000310
      LOGICAL CONVG                                                     CH000320
      COMMON /INDEX/ IDCO,IDCO2,IDF,IDH,IDH2,IDH2O,IDO,IDOH,IDO2,IDN,   CH000330
     1 IDNO,IDNO2,IDN2,IDH2O,IEQUIL,IHCPS,IPR,JJ,KNTCS,NA,NLM,          CH000340
     2 LS,NSE1,NSE2,NSK,NSM,NS1,NS2,ID(4,15)                            CH000350
     3/PARAMS/ CONVG,EMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNYCH000360
     5/SPECES/ASUM(20,3),CPSUM,HSUM,HO(14),SMW(14),SO(14),S1(14),       CH000370
     6 S2(14),Z(2,7,14)                                                 CH000380
     7/CEQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,      CH000390
     8 AS1(4,7,2),HDIV,HMAX,HMIN,PEXP(7)                               CH000400
     9/REACTS/BX(15),BX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)        CH000410
C-------------------------------------------------------------------CH000420
CHAPTER  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1 CH000430
C-------------------------------------------------------------------CH000440
      ENTRY TEMP                                                        CH000450
      SP1=1.0+STOICH                                                    CH000460
      IHCPS=2                                                           CH000470
      NS1=IDN2                                                          CH000480
      NS2=IDO2                                                          CH000490
      IF(KNTCS.GE.0) NS1=1                                              CH000500
      DO 115 JY=2,NYM1                                                  CH000510
      I=IY+IXJUY                                                        CH000520
```

```
      IF(IY.EQ.NY) GO TO 112                                                    CH000530
      IF(IY.GT.IYM.AND.IX.LE.IXM) GO TO 112                                     CH000540
      FUEL(I)=AMIN1(FUEL(I),FM(I))                                              CH000550
      FS(I,IPR)=AMAX1((FM(I)-FUEL(I))*SP1,TINY)                                 CH000560
      FS(I,IDR2)=AMAX1((FUEL(I)-(FM(I)-FSTOIC)*RFSTM)*STOICH,TINY)              CH000570
      FS(I,IDR)=FUEL(I)                                                         CH000580
      FS(I,IDR2)=FS(I,IPR)                                                      CH000590
      FM2=1.0                                                                   CH000600
      DO 105 IS=NS1,NS2                                                         CH000610
      S2(IS)=FS(I,IS)                                                           CH000620
  105 FM2=FM2-S2(IS)                                                            CH000630
      FS(I,IDN2)=FM2                                                            CH000640
      S2(IDN2)=FM2                                                              CH000650
      TK=TEM(I)                                                                 CH000660
      ENTH=H(I)/GASCON                                                          CH000670
      DO 110 IT=1,ITMAX                                                         CH000680
      CALL HCPS                                                                 CH000690
      CPMIX=CPSUM+(AC1+(AC2+(AC3+AC4*TK)*TK)*TK)*FS(I,IPR)                      CH000700
      HMIX=HSUM+TK*(AH1+(AH2+(AH3+AH4*TK)*TK)*TK)*FS(I,IPR)                     CH000710
      DTEMP=(ENTH-HMIX)/(TK*CPMIX)                                              CH000720
      TK=AMIN1(TK*(1.0+DTEMP),TMAX)                                             CH000730
      TK=AMAX1(TK,TMIN)                                                         CH000740
      IF(ABS(DTEMP).LT.EPST) GO TO 113                                          CH000750
  110 CONTINUE                                                                  CH000760
      WRITE(6,120) IX,IY,NTMAX,TK,DTEMP                                         CH000770
      GO TO 113                                                                 CH000780
  112 TEM(I)=H(I)                                                               CH000790
      GO TO 115                                                                 CH000800
  113 TEM(I)=TK                                                                 CH000810
  115 CONTINUE                                                                  CH000820
      I=NY+IXINY                                                                CH000830
      TEM(I)=H(I)                                                               CH000840
  120 FORMAT(1H0,10(1H-),2X,31HPOOR CONVERGENCE OF TEMPERATURE/13X,             CH000850
     1 7HAT IX =,I3,10H, AND IY =,I3/13X,22HNUMBER OF ITERATIONS =,I3/          CH000860
     1 13X,13HTEMPERATURE =,1PE15.6/13X,7HDTEMP =,1PE15.6/13X,                  CH000870
     2 25H*** SUBROUTINE TEMP ****/)                                            CH000880
      LABPHI=DTEM                                                               CH000890
      IF(KTEST.GT.1) CALL TEST(21)                                              CH000900
      RETURN                                                                    CH000910
C-----------------------------------------------------------------------------CH000920
CHAPTER 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 CH000930
C-----------------------------------------------------------------------------CH000940
      ENTRY DENS                                                                CH000950
      PDGSCN=PRESS/GASCON                                                       CH000960
      DO 210 IY=IYF,IYL                                                         CH000970
      I=IY+IXINY                                                                CH000980
      SM=(ASM1+(ASM2+(ASM3+ASM4*TEM(I))*TEM(I))*TEM(I))*FS(I,IPR)               CH000990
      DO 205 IS=NS1,NS2                                                         CH001000
  205 SM=SM+FS(I,IS)/SMW(IS)                                                    CH001010
  210 RHO(I)=PDGSCN/(TEM(I)*SM)                                                 CH001020
      LABPHI=JRHO                                                               CH001030
      IF(KTEST.GT.1) CALL TEST(21)                                              CH001040
```

```
      RETURN                                                                    CH001050
C-----------------------------------------------------------------------------CH001060
CHAPTER  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  CH001070
C-----------------------------------------------------------------------------CH001080
      ENTRY EQUIL                                                               CH001090
      RHDIFF=1.0/(HMAX-HMIN)                                                    CH001100
      PRATIO=PRESS*0.5E-5                                                       CH001110
      DO 325 IY=IYF,IYL                                                         CH001120
      I=IY+IXINY                                                                CH001130
      SUM=FS(I,IDF)+FS(I,IDO2)                                                  CH001140
      FPR=FS(I,IPR)                                                             CH001150
      HPR=(AH1+(AH2+(AH3+AH4*TEM(I))*TEM(I))*TEM(I))*GASCON                     CH001160
      HPR=AMAX1(HPR,HMIN)                                                       CH001170
      HPR=AMIN1(HPR,HMAX)                                                       CH001180
      KK=1                                                                      CH001190
      IF(HPR.GT.HDIV) KK=2                                                      CH001200
      HPR=(HPR-HMIN)*RHDIFF                                                     CH001210
      DO 305 II=NSE1,NSE2                                                       CH001220
      LL=II-NSE1+1                                                              CH001230
      FSII=AS1(1,LL,KK)+(AS1(2,LL,KK)+(AS1(3,LL,KK)+AS1(4,LL,KK)               CH001240
     1 *HPR)*HPR)*HPR                                                           CH001250
      FS(I,II)=FPR*EXP(FSII)*PRATIO**PEXP(LL)                                   CH001260
  305 SUM=SUM+FS(I,II)                                                          CH001270
      IF(KNTCS.EQ.0) FS(I,IDN2)=AMIN1(1.0-SUM,1.0-OXC)                          CH001280
  325 CONTINUE                                                                  CH001290
      IF(KTEST.LE.1) RETURN                                                     CH001300
      DO 330 II=NSE1,NSE2                                                       CH001310
      LABPHI=II+JS1-1                                                           CH001320
  330 CALL TEST(21)                                                             CH001330
      RETURN                                                                    CH001340
C-----------------------------------------------------------------------------CH001350
CHAPTER  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  4  CH001360
C-----------------------------------------------------------------------------CH001370
      ENTRY KINF                                                                CH001380
      PA=PRESS                                                                  CH001390
      IF(ISWEEP.EQ.KSWEEP) GO TO 484                                            CH001400
      IF(ISWEEP.EQ.(KSWEEP+1)) GO TO 485                                        CH001410
      GO TO 495                                                                 CH001420
  485 IF(IX.GT.IXW) GO TO 495                                                   CH001430
  484 IHCNY=IHC*NY                                                              CH001440
      DO 482 ISP=1,NSK                                                          CH001450
      DO 482 IY=IYF,IYL                                                         CH001460
      I=IY+IXINY                                                                CH001470
      IDP=I-IHCNY                                                               CH001480
      IDN=I+IHCNY                                                               CH001490
      FS(I,ISP)=FS(IDP,ISP)                                                     CH001500
  482 FS(IDN,ISP)=FS(I,ISP)                                                     CH001510
  495 DO 487 IY=IYF,IYL                                                         CH001520
      I=IY+IXINY                                                                CH001530
      IN=I+1                                                                    CH001540
      IS=I-1                                                                    CH001550
      IE=I+NY                                                                   CH001560
```

```
      IW=I-DY                                                          CH001570
      ENV=AL(IY)+AW(IY)+AN(IY)+AS(IY)                                  CH001580
      DO 486 ISP=IDN2,NSE2                                             CH001590
  486 S2(ISP)=FS(I,ISP)/SMW(ISP)                                       CH001600
      TK=TEM(I)                                                        CH001610
      DO 488 ISP=1,NSK                                                 CH001620
      S1(ISP)=(AN(IY)*FS(IN,ISP)+AS(IY)*FS(IS,ISP)+AW(IY)*FS(IW,ISP)   CH001630
     1 +AE(IY)*FS(IE,ISP))/(ENV*SMW(ISP))                              CH001640
  488 S2(ISP)=FS(I,ISP)/SMW(ISP)                                       CH001650
      PWR=ENRAT-0.10                                                   CH001660
      ENV=ENV/(VOL(I))**PWR                                            CH001670
      IF(TK.LE.550.0) GO TO 400                                        CH001680
      CALL SPECF                                                       CH001690
      IF(CONVC) GO TO 410                                              CH001700
      WRITE(6,481) IX,IY                                               CH001710
  481 FORMAT (10X,68HCHEMICAL KINETICS SOLUTION FAILED...AVG INLET PROPCH001720
     1RTIES RETURNED   /10X,6HAT IX=,I3,9H,AND, IY=,I3/)               CH001730
  400 DO 402 ISP=1,NSK                                                 CH001740
  402 S2(ISP)=S1(ISP)                                                  CH001750
  410 SUM=0.0                                                          CH001760
      DO 489 ISP=1,NSE2                                                CH001770
  489 SUM=SUM+S2(ISP)*SMW(ISP)                                         CH001780
      DO 490 ISP=1,NSK                                                 CH001790
  490 FS(I,ISP)=S2(ISP)*SMW(ISP)/SUM                                   CH001800
      SUM=0.0                                                          CH001810
      DO 493 ISP=1,NSE2                                                CH001820
  493 SUM=SUM+FS(I,ISP)                                                CH001830
      FS(I,IDN2)=AMTH1(1.0+FS(I,IDN2)-SUM,1.0-0XC)                     CH001840
  487 CONTINUE                                                         CH001850
      RETURN                                                           CH001860
      END                                                              CH001870
```

```
      SUBROUTINE SPECC                                                  SP000010
      LOGICAL CONVG                                                     SP000020
      DOUBLE PRECISION A,X,Y                                            SP000030
      COMMON /INDEX/ IDCO,IDCO2,IDF,IDH,IDH2,IDH2O,IDO,IDOH,IDO2,IDN,   SP000040
     1 IDNO,IDNO2,IDN2,IDN2O,IEQUIL,IHCPS,IPR,JJ,KNTCS,NA,NLM,          SP000050
     2 NS,NSE1,NSE2,NSK,NSM,NS1,NS2,ID(4,15)                            SP000060
     3/PARAMS/ CONVG,EMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNYSP000070
     5/SPECIES/ASUB(20,3),CPSUM,HSUM,H0(14),SMW(14),S0(14),S1(14),      SP000080
     6 S2(14),Z(2,7,14)                                                 SP000090
     7/EQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,       SP000100
     8 AS1(4,7,2),HDIV,HMAX,HMIN,PEXP(7)                               SP000110
     9/REACTS/BX(15),BX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)        SP000120
      COMMON/ELEMNTS/ATOM(3,7),B0(7)                                    SP000130
     1 /STOCHO/ AL(7,14)                                                SP000140
     2 /MATRIX/ A(14,15),X(15),Y(15)                                    SP000150
C-----------------------------------------------------------------------SP000160
CHAPTER 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1                  SP000170
C-----------------------------------------------------------------------SP000180
      CONVG=.FALSE.                                                     SP000190
      SM=0.0                                                            SP000200
      DO 100 IS=1,NS                                                    SP000210
      S2(IS)=AMAX1(S2(IS),TINYK)                                        SP000220
      SM=SM+S2(IS)                                                      SP000230
      Y(IS)=ALOG(S2(IS))                                                SP000240
  100 X(IS)=0.0                                                         SP000250
      X(NSM)=0.0                                                        SP000260
      Y(NSM)=ALOG(SM)                                                   SP000270
      IMAT=NSK                                                          SP000280
      KMAT=IMAT+1                                                       SP000290
C-----------------------------------------------------------------------SP000300
CHAPTER 2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2                  SP000310
C-----------------------------------------------------------------------SP000320
      DO 200 ITER=1,ITMAX                                               SP000330
      CALL CALC                                                         SP000340
      IF (IDEBUG.EQ.0) GO TO 220                                        SP000350
      WRITE (6,221)                                                     SP000360
  221 FORMAT (1H0,10X,38H ELEMENTS A(I,K) OF CORRECTION MATRIX  /)      SP000370
      DO 222 K=1,IMAT                                                   SP000380
  222 WRITE (6,223) (A(K,I),I=1,KMAT)                                   SP000390
  223 FORMAT (1H ,1P11E10.2)                                            SP000400
  220 DO 230 NN=1,IMAT                                                  SP000410
      K=NN+1                                                            SP000420
      DTM1=1.0/A(NN,NN)                                                 SP000430
      DO 225 J=K,KMAT                                                   SP000440
  225 A(NN,J)=A(NN,J)*DTM1                                              SP000450
      IF (K.EQ.KMAT) GO TO 230                                          SP000460
      DO 226 I=K,IMAT                                                   SP000470
      DO 226 J=K,KMAT                                                   SP000480
  226 A(I,J)=A(I,J)-A(I,NN)*A(NN,J)                                     SP000490
  230 CONTINUE                                                          SP000500
      K=IMAT                                                            SP000510
                                                                        SP000520
```

```
  235 J=K+1                                                              SP000530
      SUM=0.0                                                            SP000540
      X(K)=0.0                                                           SP000550
      IF (IMAT.LT.J) GO TO 240                                           SP000560
      DO 236 I=J,IMAT                                                    SP000570
  236 SUM=SUM+A(K,I)*X(I)                                                SP000580
  240 X(K)=A(K,IMAT)-SUM                                                 SP000590
      K=K-1                                                              SP000600
      IF (K.NE.0) GO TO 235                                              SP000610
C-----------------------------------------------------------------------SP000620
CHAPTER  3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   3   SP000630
C-----------------------------------------------------------------------SP000640
      ETA1=1.                                                            SP000650
      SUM=TINYK                                                          SP000660
      DO 300 IS=1,NSK                                                    SP000670
      IF (X(IS).LE.0.0) GO TO 300                                        SP000680
      SUM=AMAX1(X(IS),SUM)                                               SP000690
      IF(S2(IS)/SM.LE.1.E-8)                                             SP000700
     1 ETA1=AMIN1(ABS(Y(NSM)-Y(IS)-9.212)/X(IS),ETA1)                    SP000710
  300 CONTINUE                                                           SP000720
      ETA=AMIN1(ETA1,2.0/SUM)                                            SP000730
C-----------------------------------------------------------------------SP000740
CHAPTER  4   4   4   4   4   4   4   4   4   4   4   4   4   4   4   4   SP000750
C-----------------------------------------------------------------------SP000760
      DO 400 IS=1,NSK                                                    SP000770
      Y(IS)=Y(IS)+ETA*X(IS)                                              SP000780
      Y(IS)=AMAX1(Y(IS),TINY)                                            SP000790
  400 S2(IS)=EXP(Y(IS))                                                  SP000800
      IF(IDEB.G.NE.0)WRITE(6,410)ITER,ETA,(ASUB(K,1),S2(K),Y(K),X(K),    SP000810
     1 K=1,NSK)                                                          SP000820
  410 FORMAT(1H0,6HITER =,I3,5X,5HETA =,1PE10.3//17X,2HS2,12X,5HLOGS2,   SP000830
     1 8X,4HB(LOGS2)//(5X,A4,1P3E15.6))                                  SP000840
C-----------------------------------------------------------------------SP000850
CHAPTER  5   5   5   5   5   5   5   5   5   5   5   5   5   5   5   5   SP000860
C-----------------------------------------------------------------------SP000870
      IF (ETA.LT.1.) GO TO 200                                           SP000880
      DO 510 IS=1,NSK                                                    SP000890
      IF (S2(IS).LE.TINYK*1.001) GO TO 510                               SP000900
      IF (ABS(X(IS)).GT.EPSS) GO TO 200                                  SP000910
  510 CONTINUE                                                           SP000920
      CONVG=.TRUE.                                                       SP000930
      RETURN                                                             SP000940
  200 CONTINUE                                                           SP000950
      RETURN                                                             SP000960
      END                                                                SP000970
```

```
                                                                      CA000010
      SUBROUTINE CALC                                                 CA000020
      LOGICAL CONVG                                                   CA000030
      DOUBLE PRECISION A,X,Y                                          CA000040
      COMMON /INDEX/ IDCO,IDCO2,IDF,IDH,IDH2,IDH2O,IDO,IDOH,IDO2,IDM, CA000050
     1 IDMO,IDMO2,IDM2,IDM2O,IEQUIL,IHCPS,IPP,JJ,KNTCS,NA,NLM,        CA000060
     2 NS,NSE1,NSE2,NSK,NSM,NS1,NS2,ID(4,15)                          CA000070
     3/PARAMS/ CONVG,EMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNYCA000080
     5/SPECIES/ASUB(20,3),CPSUM,HSUM,HO(14),SMW(14),SO(14),S1(14),    CA000090
     6 S2(14),Z(2,7,14)                                               CA000100
     7/EQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,     CA000110
     8 AS1(4,7,2),IDIV,HMAX,HMIN,PEXP(7)                             CA000120
     9/REACTS/BX(15),EX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)      CA000130
      COMMON/ELEMNTS/ATOM(3,7),BO(7)                                  CA000140
     1 /STOICH/ AL(7,14)                                              CA000150
     2 /MAIRI/ A(14,15),X(15),Y(15)                                   CA000160
C-----------------------------------------------------------------------CA000170
CHAPTER  1   1   1   1   1   1   1   1   1   1   1   1   1   1   1   1  CA000180
C-----------------------------------------------------------------------CA000190
      NSK1=NSK+1                                                      CA000200
      DO 10 I=1,NS                                                    CA000210
      DO 10 K=1,NA                                                    CA000220
   10 A(I,K)=0.0                                                      CA000230
      RHSP=PA/(GASCON*TK)                                             CA000240
      TKINV=1.0/TK                                                    CA000250
      RHOP=RHOM/SM                                                    CA000260
      RHSO=RHSP*RHOP                                                  CA000270
      RHSMP=RHSM*RHOP                                                 CA000280
      RHSMSQ=RHSM*RHSO                                                CA000290
C-----------------------------------------------------------------------CA000300
CHAPTER  2   2   2   2   2   2   2   2   2   2   2   2   2   2   2   2  CA000310
C-----------------------------------------------------------------------CA000320
      DO 200 J=1,JJ                                                   CA000330
      R1=BX(J)*EXP(-TACT(J)*TKINV)*TK**TEN(J)                         CA000340
      R2=BX2(J)*EXP(-TACT2(J)*TKINV)*TK**TEN2(J)                      CA000350
      I=ID(1,J)                                                       CA000360
      K=ID(2,J)                                                       CA000370
      M=ID(3,J)                                                       CA000380
      N=ID(4,J)                                                       CA000390
      IF (K.EQ.0) GO TO 20                                            CA000400
      IF (M.EQ.0) GO TO 30                                            CA000410
      MODE=1                                                          CA000420
      R1=(RHSO*S2(I))*(R1*S2(K))                                      CA000430
      R2=(RHSO*S2(M))*(R2*S2(N))                                      CA000440
      GO TO 40                                                        CA000450
   20 MODE=2                                                          CA000460
      R1=RHSMP*R1*S2(I)                                               CA000470
      R2=RHSMSQ*S2(M)*R2*S2(N)                                        CA000480
      GO TO 40                                                        CA000490
   30 MODE=3                                                          CA000500
      R1=RHSMSQ*S2(I)*R1*S2(K)                                        CA000510
      R2=RHSMP*R2*S2(M)                                               CA000520
```

```
   40 TM1=R1-R2                                                          CA000530
      A(I,I)=A(I,I)+R1                                                   CA000540
      A(M,I)=A(M,I)-R1                                                   CA000550
      A(I,K)=A(I,K)-R2                                                   CA000560
      A(M,K)=A(M,K)+R2                                                   CA000570
      A(I,NA)=A(I,NA)-TM1                                                CA000580
      A(M,NA)=A(M,NA)+TM1                                                CA000590
      IF (MODE.EQ.3) GO TO 50                                            CA000600
      A(N,I)=A(N,I)-R1                                                   CA000610
      A(N,K)=A(N,K)+R2                                                   CA000620
      A(I,K)=A(I,K)-R2                                                   CA000630
      A(M,K)=A(M,K)+R2                                                   CA000640
      A(N,K)=A(N,K)+R2                                                   CA000650
      A(N,NA)=A(N,NA)+TM1                                                CA000660
      IF (MODE.EQ.2) GO TO 200                                           CA000670
   50 A(K,I)=A(K,I)+R1                                                   CA000680
      A(I,K)=A(I,K)+R1                                                   CA000690
      A(K,K)=A(K,K)+R1                                                   CA000700
      A(M,K)=A(M,K)-R1                                                   CA000710
      A(K,K)=A(K,K)-R2                                                   CA000720
      A(K,NA)=A(K,NA)-TM1                                                CA000730
      IF (MODE.EQ.3) GO TO 200                                           CA000740
      A(N,K)=A(N,K)-R1                                                   CA000750
      A(K,K)=A(K,K)-R2                                                   CA000760
  200 CONTINUE                                                           CA000770
C-------------------------------------------------------------------------CA000780
CHAPTER 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3                                CA000790
C-------------------------------------------------------------------------CA000800
      DO 300 IS=1,NSK                                                    CA000810
      A(IS,IS)=A(IS,IS)+ENV*S2(IS)                                       CA000820
  300 A(IS,NSK1)=A(IS,NA)+ENV*(S1(IS)-S2(IS))                            CA000830
      RETURN                                                             CA000840
      END                                                                CA000850
```

```
                                                                        C0000010
      SUBROUTINE CONST(KGOTO)                                           C0000020
      COMMON/COMA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),    C0000030
     1 TP(20),TEM(500),P(414),RHO(500),LMU(500),                        C0000040
     1 GXG(25),GXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),   C0000050
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                          C0000060
     3 A(20),AE(20),AU(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),     C0000070
     4 BSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),           C0000080
     5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),      C0000090
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),       C0000100
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),    C0000110
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),           C0000120
     9 ANDDY(500),AREAN(500),VOL(500),                                  C0000130
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),             C0000140
     1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),        C0000150
     2 RSREF(25),RSSUM(25),TITLE(25)                                    C0000160
      DIMENSION DIFNW(20),DIFWW(20),F(11809),FLOWNW(20),FLOWWW(20)      C0000170
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),          C0000180
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))               C0000190
      COMMON/COMB/                                                      C0000200
     1 AK,ARROW,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,      C0000210
     2 EPST,ERAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,           C0000220
     3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,        C0000230
     4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,          C0000240
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,     C0000250
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,       C0000260
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,     C0000270
     8 LABEL1,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,     C0000280
     9 NXM2,NXYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OX8,OXC,PJAY,        C0000290
     X PRELXP,PRESS,RELAXP,RF,RFSTM,RSCHEK,RSMAX,R1I,R1O,R2I,R2O,       C0000300
     1 STOICH,TR,TC,TINY,TMAX,TMIN,UB,UC,WMIX                           C0000310
C ---------------------- CONSTANTS RELATED TO NX AND NY ---------------- C0000320
      IF (KGOTO.NE.2) GO TO 3000                                        C0000330
      NXM1=NX-1                                                         C0000340
      NXM2=NX-2                                                         C0000350
      NYM1=NY-1                                                         C0000360
      NYM2=NY-2                                                         C0000370
C ---------------------- TOTAL NUMBER OF NODES FOR DIFFERENT VARIABLES  C0000380
      NXYG=NX*NY                                                        C0000390
      NXYP=NX*2*NYM2                                                    C0000400
      NXYU=NX*1*NY                                                      C0000410
      NXYV=NX*NYM1                                                      C0000420
      RETURN                                                            C0000430
C ----------------------CONSTANTS RELATED TO VARIABLES ----------------C0000440
 3000 IF (KGOTO.NE.3) GO TO 5000                                        C0000450
      KRHOMU=KSOLVE(JRHO)+KSOLVE(JEMU)                                  C0000460
C ---------------------- IZERO,ILAST AND IEW FOR DIFFERENT VARIABLES    C0000470
      IZERO(1)=0                                                        C0000480
      DO 35 J=1,JLAST                                                   C0000490
      IF(J-JU) 310,301,310                                              C0000500
310   IF(J-JV)320,302,320                                               C0000510
320   IF(J-JP)330,303,330                                               C0000520
```

```
300   IF (J-JPP) 305,304,305                                          C0000530
301   IL=NXYU                                                         C0000540
      ILMAX=(NXMAX-1)*NYMAX                                           C0000550
      IEW(J)=NY                                                       C0000560
      GO TO 34                                                        C0000570
302   IL=NXYV                                                         C0000580
      ILMAX=NXMAX*(NYMAX-1)                                           C0000590
      IEW(J)=NY+1                                                     C0000600
      GO TO 34                                                        C0000610
303   IL=NXYP                                                         C0000620
      ILMAX=(NXMAX-2)*(NYMAX-2)                                       C0000630
      IEW(J)=NY-2                                                     C0000640
      GO TO 34                                                        C0000650
304   IL=NY                                                           C0000660
      ILMAX=NYMAX                                                     C0000670
      IEW(J)=0                                                        C0000680
      GO TO 34                                                        C0000690
305   IL=NXYG                                                         C0000700
      ILMAX=NXMAX*NYMAX                                               C0000710
      IEW(J)=NY                                                       C0000720
34    ILAST(J)=IZERO(J)+IL                                            C0000730
      IF(J.EQ.JLAST) GO TO 35                                         C0000740
      JP1=J+1                                                         C0000750
      IZERO(JP1)=IZERO(J)+ILMAX                                       C0000760
35    CONTINUE                                                        C0000770
      RETURN                                                          C0000780
C---------------------- CONSTANTS RELATED TO CHAP. 5 OF MAIN  ---------C0000790
 5000 IF (KGOTO.NE.5) RETURN                                          C0000800
      IPREF=IYPREF-1+(IXPREF-2)*NYM2                                  C0000810
      DO 56 J=1,JLAST                                                 C0000820
      IF(J.EQ.JPP) GO TO 56                                           C0000830
      IMON(J)=IYMON+(IXMON-1)*ILW(J)                                  C0000840
      IF(J.EQ.JP) IMON(J)=IYMON-1+(IXMON-2)*IEW(J)                    C0000850
56    CONTINUE                                                        C0000860
      RETURN                                                          C0000870
      END                                                             C0000880
```

```
                                                                        GE000010
      SUBROUTINE GEOM                                                   GE000020
C-----------------------------------------------------------------------GE000030
CHAPTER 0  0  0  0  0  0  0    DECLARATIONS    0  0  0  0  0  0  0  0   GE000040
C                                                                       GE000050
      COMMON/COMA/ U(480),V(475),H(500),EM(500),EUE(500),FS(500,15),    GE000060
     1 PP(20),TEM(500),P(414),RHO(500),EMU(500),                        GE000070
     1 DXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),   GE000080
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                          GE000090
     3 A(20),AF(20),AN(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),     GE000100
     4 BSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),           GE000110
     5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),      GE000120
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),       GE000130
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),    GE000140
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),           GE000150
     9 ANDDY(500),AREAN(500),VOL(500),                                  GE000160
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),             GE000170
     1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),        GE000180
     2 RSREF(25),RSSUM(25),TITLE(25)                                    GE000190
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)      GE000200
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),          GE000210
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))               GE000220
      COMMON/COMB/                                                      GE000230
     1 AK,ARROW,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,      GE000240
     2 EPST,EWRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,          GE000250
     3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,        GE000260
     4 ISWEEP,IX,IXMON,IXPRLF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,          GE000270
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,     GE000280
     6 IYPRLF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,       GE000290
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,     GE000300
     8 LABPRI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,     GE000310
     9 NXM2,NYYU,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,        GE000320
     X PRELAP,PRESS,RELAXP,RF,RESTM,RSCHEK,RSMAX,R1I,R1O,R2I,R2O,       GE000330
     1 STOICH,TB,TC,TINY,TMAX,TMIN,UB,UC,WMIX                           GE000340
C                                                                       GE000350
C-----------------------------------------------------------------------GE000360
CHAPTER 1  1  1  1  1  1  1    RADII    1  1  1  1  1  1  1  1  1  1     GE000370
C-----------------------------------------------------------------------GE000380
      DO 26 IY=1,NY                                                     GE000390
26    R(IY)=Y(IY)                                                       GE000400
C-----------------------------------------------------------------------GE000410
CHAPTER 2  2  2  2  2  2  2   CELL-NODE DISTANCES   2  2  2  2  2  2  2 GE000420
C-----------------------------------------------------------------------GE000430
C------------------------------------------ GRID-NODE DISTANCES          GE000440
      DXG(1)=0.0                                                        GE000450
      DYG(1)=0.0                                                        GE000460
      DO 30 IX=2,NX                                                     GE000470
      DXG(IX)=X(IX)-X(IX-1)                                             GE000480
30    RDXG(IX)=1./DXG(IX)                                               GE000490
      DO 31 IY=2,NY                                                     GE000500
      DYG(IY)=Y(IY)-Y(IY-1)                                             GE000510
31    RDYG(IY)=1./DYG(IY)                                               GE000520
```

```
C------------------------------------------ U-NODE DISTANCES                GE000530
      XU(1)=X(1)                                                           GE000540
      DO 32 IX=2,NXM2                                                      GE000550
32    XU(IX)=0.5*(X(IX)+X(IX+1))                                           GE000560
      XU(NX+1)=X(NX)                                                       GE000570
      XU(NX)=X(NX)                                                         GE000580
      DXU(1)=0.0                                                           GE000590
      DO 33 IX=2,NXM1                                                      GE000600
      DXU(IX)=XU(IX)-XU(IX-1)                                              GE000610
33    RDXU(IX)=1./DXU(IX)                                                  GE000620
      DXU(NX)=0.0                                                          GE000630
C---------------------- V-NODE DISTANCES ANd V-CELL BoUNDARY RADII        GE000640
      YV(1)=Y(1)                                                           GE000650
      RV(1)=R(1)                                                           GE000660
      RVCB(1)=R(1)                                                         GE000670
      RVSQ(1)=RV(1)**2                                                     GE000680
      DO 34 IY=2,NYM2                                                      GE000690
      YV(IY)=0.5*(Y(IY)+Y(IY+1))                                           GE000700
      RV(IY)=0.5*(R(IY)+R(IY+1))                                           GE000710
      RVSQ(IY)=RV(IY)**2                                                   GE000720
34    RVCB(IY)=R(IY)                                                       GE000730
      RVCB(2)=R(1)                                                         GE000740
      YV(NY-1)=Y(NY)                                                       GE000750
      RV(NY-1)=R(NY)                                                       GE000760
      RVCB(NY-1)=R(NY)                                                     GE000770
      RVSQ(NY-1)=RV(NY-1)**2                                               GE000780
      YV(NY)=Y(NY)                                                         GE000790
      RV(NY)=R(NY)                                                         GE000800
      RVCB(NY)=R(NY)                                                       GE000810
      RVSQ(NY)=RV(NY)**2                                                   GE000820
      DYV(1)=0.0                                                           GE000830
      DO 35 IY=2,NYM1                                                      GE000840
      DYV(IY)=YV(IY)-YV(IY-1)                                              GE000850
35    RDYV(IY)=1./DYV(IY)                                                  GE000860
      DYV(NY)=0.0                                                          GE000870
C--------------------------------------------------------------------------GE000880
CHAPTER 3  3  3  3  3  3    CELL DIMENSIONS  3  3  3  3  3  3  3  3        GE000890
C--------------------------------------------------------------------------GE000900
C------------------------------------ GRID-NODE CELLS                      GE000910
      SXG(1)=1.0                                                           GE000920
      DO 40 IX=3,NXM2                                                      GE000930
40    SXG(IX)=0.5*(DXG(IX)+DXG(IX+1))                                      GE000940
      SXG(2)=DXG(2)+0.5*DXG(3)                                             GE000950
      SXG(NXM1)=0.5*DXG(NXM1)+DXG(NX)                                      GE000960
      SXG(NX)=0.0                                                          GE000970
      DO 49 IX=1,NX                                                        GE000980
      IX1NY=(IX-1)*NY                                                      GE000990
      DO 49 IY=1,NY                                                        GE001000
      I=IY+IX1NY                                                           GE001010
   49 AREA(I)=SXG(IX)*RV(IY)                                               GE001020
      SYG(1)=0.0                                                           GE001030
      DO 41 IY=3,NYM2                                                      GE001040
```

```
41    SYG(IY)=0.5*(DYG(IY)+DYG(IY+1))                                  GE001050
      SYG(1)=0.0                                                       GE001060
      SYG(2)=SYG(2)+0.5*DYG(3)                                         GE001070
      SYG(NYM1)=DYG(NY)+0.5*DYG(NYM1)                                  GE001080
      DO 45 IX=2,NXM1                                                  GE001090
45    RSXG(IX)=1./SXG(IX)                                              GE001100
      DO 46 IY=2,NYM1                                                  GE001110
      AREAE(IY)=.5*(RV(IY)+RV(IY-1))*SYG(IY)                           GE001120
46    RSYG(IY)=1./SYG(IY)                                              GE001130
      AREAF(1)=0.0                                                     GE001140
      AREAE(NY)=0.0                                                    GE001150
C------------------------------------- U-VELOCITY CELLS                GE001160
      SXU(1)=0.0                                                       GE001170
      DO 42 IX=2,NXM2                                                  GE001180
42    SXU(IX)=X(IX+1)-X(IX)                                            GE001190
      SXU(2)=SXU(2)+DXG(2)                                             GE001200
      SXU(NXM2)=SXU(NXM2)+DXG(NX)                                      GE001210
      SXU(NXM1)=0.0                                                    GE001220
      SXU(NX)=0.0                                                      GE001230
      DO 47 IX=2,NXM2                                                  GE001240
47    RSXU(IX)=1./SXU(IX)                                              GE001250
C-------------------------V-VELOCITY CELLS                             GE001260
      SYV(1)=0.0                                                       GE001270
      DO 43 IY=2,NYM2                                                  GE001280
43    SYV(IY)=Y(IY+1)-Y(IY)                                            GE001290
      SYV(2)=SYV(2)+DYG(2)                                             GE001300
      SYV(NYM2)=SYV(NYM2)+DYG(NY)                                      GE001310
      SYV(NYM1)=0.0                                                    GE001320
      SYV(NY)=0.0                                                      GE001330
      DO 48 IY=2,NYM2                                                  GE001340
48    RSYV(IY)=1./SYV(IY)                                              GE001350
      DO 405 IX=2,NXM1                                                 GE001360
      IX1NY=(IX-1)*NY                                                  GE001370
      IF=1+IX1NY                                                       GE001380
      AREDY(IF)=ARLAN(IF)*RDYG(2)                                      GE001390
      DO 405 IY=2,NYM1                                                 GE001400
      I=IY+IX1NY                                                       GE001410
      AREDX(I)=AREAF(IY)*RDXG(IX+1)                                    GE001420
      AREDY(I)=AREAN(I)*RDYG(IY+1)                                     GE001430
405   VOL(I)=AREAE(IY)*SXG(IX)                                         GE001440
      IXL=(NX-1)*NY                                                    GE001450
      DO 407 IY=1,NY                                                   GE001460
      I1=IY                                                            GE001470
      IL=IY+IXL                                                        GE001480
      AREDX(I1)=0.0                                                    GE001490
407   AREDX(IL)=0.0                                                    GE001500
      RETURN                                                           GE001510
      END                                                              GE001520
```

```
      SUBROUTINE ADJUST(KGOTO)                                          AD000020
      COMMON/ADJA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),    AD000030
     1 PP(20),T M(500),P(414),RHO(500),EMU(500),                        AD000040
     1 XG(25), XU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),    AD000050
     2 STOP( 5),SXG(25),SXU(25),X(25),XU(25),                           AD000060
     3 P(20),E(20),AP(20),ARLAE(20),AS(20),ASNIP(20),AW(20),B(20),      AD000070
     4 DSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),           AD000080
     5 DIFEE(20),DIFU(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),      AD000090
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),       AD000100
     7 DYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),     AD000110
     8 SP(20),SP(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),           AD000120
     9 AHDDY(500),ARLAM(500),VOL(500),                                  AD000130
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),             AD000140
     1 TEW(25),TLAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),        AD000150
     2 KSRT(25),RSSUM(25),TILL(25)                                      AD000160
      DIMENSION DIFN(20),DIFNW(20),F(11889),FLOWNW(20),FLOWWW(20)       AD000170
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),          AD000180
     1 FLOWE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))                AD000190
      COMMON/COMB/                                                      AD000200
     1 AK,AKRSQ,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,      AD000210
     2 EPSI,ERAT,LWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,           AD000220
     3 ISTOIM,IUB,IUC,HIU,HW,INC,INCRI,IPLRS,IPREF,IPRINT,ISNIP,        AD000230
     4 ISWEEP,IT,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,          AD000240
     5 IX1NY1,IX2NY,IX2NY1,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,AD000250
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,       AD000260
     7 JS1,JS2,JTEM,JU,JV,KASE,KINFRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,     AD000270
     8 LADPHI,LSWEEP,NSOLVE,NIDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,     AD000280
     9 NXM2,NXY2,NXYF,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,        AD000290
     X PRESP,PRESS,PRLAXP,RF,RFSTM,RSCHEK,RSMAX,R11,R10,R21,R20,        AD000300
     1 STOICH,TU,TC,TJHY,TMAX,TMIN,UB,UC,WMIX                           AD000310
C-----------------------------------------------------------------------AD000320
CHAPTER 1  1  1  1  1  OVERALL-CONTINUITY CORRECTION  1  1  1  1  1  1  AD000330
C-----------------------------------------------------------------------AD000340
      IF (KGOTO-2) 1000,2000,3000                                       AD000350
C                                                                       AD000360
C            CORRECTION TO U'S ON IXU LINE                              AD000370
C----------------------CALCULATE DELU                                   AD000380
 1000 FLOWST=0.0                                                        AD000390
      SRHOA=0.0                                                         AD000400
      IF(INC.EQ.-1) GO TO 105                                           AD000410
      DO 100 IY=IYF,IYL                                                 AD000420
      IF(DSNIP(IY).GT.1.0E08) GO TO 100                                 AD000430
      I=IY+IX1NYU                                                       AD000440
      SRHOA=SRHOA+FLOWE(IY)/(U(I)+TINY)                                 AD000450
      FLOWST=FLOWST+FLOWE(IY)                                           AD000460
  100 CONTINUE                                                          AD000470
      GO TO 107                                                         AD000480
C                                                                       AD000490
  105 DO 1011 IY=IYF,IYL                                                AD000500
      IF(DSNIP(IY).GT.1.0E08) GO TO 1011                                AD000510
      I=IY+IX1NYU                                                       AD000520
```

```
      SRHOA=SRHOA+FLOWW(IY)/(U(I)+TINY)                                 AD000530
      FLOWST=FLOWST+FLOWW(IY)                                           AD000540
 1011 CONTINUE                                                          AD000550
  107 DELU=(FLOWUP-FLOWST)/SRHOA                                        AD000560
C-----------------------ADD DELU TO U'S ON IXU LINE                     AD000570
      DO 101 IY=IYF,IYL                                                 AD000580
      IF(USKIP(IY).GT.1.0E08) GO TO 101                                 AD000590
      I=IY+IXINYU                                                       AD000600
      U(I)=U(I)+DELU                                                    AD000610
  101 CONTINUE                                                          AD000620
      RETURN                                                            AD000630
C-----------------------------------------------------------------------AD000640
CHAPTER 2   2   2   2   CELL-WISE CONTINUITY CORRECTION 2   2   2   2   AD000650
C-----------------------------------------------------------------------AD000660
 2000 CONTINUE                                                          AD000670
      IF(KSOLVE(JU).EQ.0) GO TO 200                                     AD000680
C-------------CORRECT U'S ON TDMA LINE                                  AD000690
      DO 21 IY=IYF,IYL                                                  AD000700
      I=IY+IXINYU                                                       AD000710
   21 U(I)=U(I)+DU(IY)*PP(IY)*FLOAT(INC)                                AD000720
C------------------------------------  CORRECT V'S ON TDMA LINE         AD000730
200   IF(KSOLVE(JV).EQ.0) GO TO 210                                     AD000740
      DO 201 IY=IYF,IYLM1                                               AD000750
      IV=IY+IXINY1                                                      AD000760
201   V(IV)=V(IV)+DV(IY)*(PP(IY)-PP(IY+1))                              AD000770
C--------------------------------          CORRECT P'S ON TDMA LINE     AD000780
  210 ICONST=IX*NY2-1                                                   AD000790
      SUM=0.0                                                           AD000800
      AREA=0.0                                                          AD000810
      DO 22 IY=IYF,IYL                                                  AD000820
      PP(IY)=PP(IY)*RELAXP                                              AD000830
      SUM=SUM+PP(IY)*AREAE(IY)                                          AD000840
   22 AREA=AREA+AREAE(IY)                                               AD000850
      DELPP=-SUM/AREA                                                   AD000860
      DO 211 IY=IYF,IYL                                                 AD000870
      IP=IY+ICONST                                                      AD000880
  211 P(IP)=P(IP)+PP(IY)+DELPP                                          AD000890
      RETURN                                                            AD000900
C-----------------------------------------------------------------------AD000910
CHAPTER  3  3  3  3  OVERALL-MOMENTUM CORRECTION - SNIP  3  3  3  3  3  AD000920
C-----------------------------------------------------------------------AD000930
 3000 IXM1=IX-1                                                         AD000940
      SUM=0.0                                                           AD000950
      AREA=0.0                                                          AD000960
      ICONST=IX*NYU-1                                                   AD000970
      DO 302 IY=IYF,IYL                                                 AD000980
      IF(USKIP(IY).GT.1.0E08) GO TO 302                                 AD000990
      I=IY+IXINYU                                                       AD001000
      IE=I+1                                                            AD001010
      IS=I-1                                                            AD001020
      IP=IY+ICONST                                                      AD001030
      IEP=IP+NY*2                                                       AD001040
```

```
      APEA=ARE A+ARE AE(IY)                                                    AD001050
      SUM=SUM+DSNIP(IY)*U(I)-ASNIP(IY)*U(IM)-BSNIP(IY)*U(IS)-CSNIP(IY)         AD001060
     1 -ARE AE(I,)*(P(IP)-P(IEP))                                              AD001070
  302 CONTINUE                                                                 AD001080
C                                                                              AD001090
      DE=-SUM/AREA                                                             AD001100
      DP=AMAX1(DP,-5.0)                                                        AD001110
      DP=AMIN1(DP,5.0)                                                         AD001120
C                                                                              AD001130
      IF(IPC.EQ.1) GO TO 303                                                   AD001140
      IF(IXU.E.E.IXW) GO TO 304                                                AD001150
      DO 315 IXX=2,IXU                                                         AD001160
      IXXNY2=(IXX-2)*NYM2-1                                                    AD001170
      DO 315 IY=2,NYM1                                                         AD001180
      I=IY+IXXNY2                                                              AD001190
  315 P(I)=P(I)-DP                                                             AD001200
      GO TO 310                                                                AD001210
C                                                                              AD001220
  304 DO 306 IXX=2,IXU                                                         AD001230
      IXXNY2=(IXX-2)*NYM2-1                                                    AD001240
      DO 306 IY=IYWP1,NYM1                                                     AD001250
      I=IY+IXXNY2                                                              AD001260
  306 P(I)=P(I)-DP                                                             AD001270
      GO TO 310                                                                AD001280
C                                                                              AD001290
  303 DO 308 IXX=IXP1,IXM1                                                     AD001300
      IXXNY2=(IXX-2)*NYM2-1                                                    AD001310
      DO 303 IY=2,NYM1                                                         AD001320
      I=IY+IXXNY2                                                              AD001330
  308 P(I)=P(I)+DP                                                             AD001340
C                                                                              AD001350
      IF(IX.GT.IXW) GO TO 310                                                  AD001360
      DO 309 IXX=2,IX                                                          AD001370
      IXXNY2=(IXX-2)*NYM2-1                                                    AD001380
      DO 309 IY=IYWP1,NYM1                                                     AD001390
      I=IY+IXXNY2                                                              AD001400
  309 P(I)=P(I)+DP                                                             AD001410
  310 RETURN                                                                   AD001420
      END                                                                      AD001430
```

```
      SUBROUTINE FLOWM(KGOTO)                                                  FL000010
      COMMON/COMA/ U(480),V(475),H(500),EM(500),EUE(500),FS(500,15),           FL000020
     1 HP(20),TEM(500),P(414),RHO(500),EMU(500),                               FL000030
     1 DXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),          FL000040
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                                 FL000050
     3 A(20),AE(20),AU(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),            FL000060
     4 CSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),                  FL000070
     5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),             FL000080
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),             FL000090
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),           FL000100
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),                  FL000110
     9 ANDDY(500),AREAN(500),VOL(500),                                         FL000120
     X ARSL(25,25),PPEFF(25),PRL(25),PRT(25),RSLINE(25,25),                    FL000130
     1 IEX(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),               FL000140
     2 KSREF(25),RSSUM(25),TITLE(25)                                           FL000150
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)             FL000160
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),                 FL000170
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))                      FL000180
      COMMON/COMB/                                                             FL000190
     1 AK,ARELOW,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,            FL000200
     2 EPST,ERAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,                  FL000210
     3 FSTOTM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,               FL000220
     4 ISWEEP,IY,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,                 FL000230
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,            FL000240
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,              FL000250
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,           FL000260
     8 LARPHI,LSWEEP,MSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,           FL000270
     9 NXM2,NXYS,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,              FL000280
     X PRELXP,PRESS,RELAXP,RF,RESTM,RSCHEK,RSMAX,R1I,R10,R21,R20,             FL000290
     1 STOICH,T3,TC,TINY,TMAX,TMIN,UB,UC,WMIX                                 FL000300
C-----------------------------------------------------------------------     FL000310
      IF(KGOTO-2) 1000,2000,3000                                               FL000320
C                                                                              FL000330
C              MASS FLOW RATES FOR CONTINUITY CELL FACES                       FL000340
C                                                                              FL000350
 1000 IF(IHC.LQ.-1) GO TO 102                                                  FL000360
C     EAST FACE OF (IX+1) CELL                                                 FL000370
      IF(IXP1.EQ.NXM1)  GO TO 101                                              FL000380
      IXXNY=IX1NY+NY                                                           FL000390
      DO 10 IY=2,NYM1                                                          FL000400
      IE=IY+IXXNY                                                              FL000410
      IEE=IE+NY                                                                FL000420
      RHOU=RHO(IE)                                                             FL000430
      IF (U(IE).LT.0.0) RHOU=RHO(IEE)                                          FL000440
      FLOWE(IY)=RHOU*U(IE)*AREAE(IY)                                           FL000450
C     NORTH FACE OF (IX+1) CELL                                                FL000460
      IV=IY+IX1NY1                                                             FL000470
      IEV=IV+NY+1                                                              FL000480
      RHOV=RHO(IE)                                                             FL000490
      IF (V(IEV).LT.0.0) RHOV=RHO(IE+1)                                        FL000500
   10 FLOWN(IY)=RHOV*V(IEV)*AREAN(IE)                                          FL000510
                                                                               FL000520
```

```
      IE=IYFM1+IXXNY                                                    FL000530
      IEV=IYF 1+IX1NY1+NY+1                                             FL000540
      RHOV=RHO(IE)                                                      FL000550
      IF (V(IEV).LT.0.0) RHOV=RHO(IE+1)                                 FL000560
      FLOW(IYFM1)=RHOV*V(IEV)*AREAN(IE)                                 FL000570
      GO TO 1 1                                                         FL000580
C                                                                       FL000590
  102 IF(I.EQ.1) GO TO 101                                              FL000600
      IXNY=IX1NY-NY                                                     FL000610
      DO 11 IY=2,NYM1                                                   FL000620
      IW=IY+IXNY                                                        FL000630
      IWW=IW-NY                                                         FL000640
      RHOU=RHO(IWW)                                                     FL000650
      IF(U(IW).LT.0.0) RHOU=RHO(IW)                                     FL000660
      FLOW(IY)=RHOU*U(IWW)*AREAE(IY)                                    FL000670
      IV=IY+1+IX1NY1                                                    FL000680
      IVV=IV-NY+1                                                       FL000690
      RHOV=RHO(IW)                                                      FL000700
      IF(V(IWV).LT.0.0) RHOV=RHO(IW+1)                                  FL000710
   11 FLOW(IY)=RHOV*V(IWV)*AREAN(IW)                                    FL000720
      IE=IYFM1+IXXNY                                                    FL000730
      IEV=IYF 1+IX1NY1-NYM1                                             FL000740
      RHOV=RHO(IW)                                                      FL000750
      IF(V(IWV).LT.0.0) RHOV=RHO(IW+1)                                  FL000760
      FLOW(IYFM1)=RHOV*V(IWV)*AREAN(IW)                                 FL000770
C     NORTH FACE OF IX CELL                                             FL000780
  101 I=IYFM1+IX1NY                                                     FL000790
      IV=IYFM1+IX1NY1                                                   FL000800
      RHOV=RHO(I)                                                       FL000810
      IF (V(IV).LT.0.0) RHOV=RHO(I+1)                                   FL000820
       FLOW(IYFM1)=RHOV*V(IV)*AREAN(I)                                  FL000830
      DO 12 IY=2,NYM1                                                   FL000840
      IV=IY+IX1NY1                                                      FL000850
      I=IY+IXNY                                                         FL000860
      RHOV=RHO(I)                                                       FL000870
      IF (V(IV).LT.0.0) RHOV=RHO(I+1)                                   FL000880
   12 FLOW(IY)=RHOV*V(IV)*AREAN(I)                                      FL000890
      RETURN                                                            FL000900
C                                                                       FL000910
 2000 CONTINUE                                                          FL000920
C                                                                       FL000930
      IF(IREC.EQ.-1) GO TO 21                                           FL000940
C     EAST FACE OF IX CELL                                              FL000950
      DO 20 IY=2,NYM1                                                   FL000960
      I=IY+IXNY                                                         FL000970
      IL=I+NY                                                           FL000980
      RHOU=RHO(I)                                                       FL000990
      IF (U(I).LT.0.0) RHOU=RHO(IL)                                     FL001000
   20 FLOW(IY)=RHOU*U(I)*AREAE(IY)                                      FL001010
      RETURN                                                            FL001020
C                                                                       FL001030
   21 DO 22 IY=2,NYM1                                                   FL001040
```

```
      I=IY+IX1DY                                                    FL001050
      IW=I-DY                                                       FL001060
      RHOU=RHO(IW)                                                  FL001070
      IF(U(IW).LT.0.0) RHOU=RHO(I)                                  FL001080
   22 FLOWW(IY)=RHOU*U(IW)*AREAE(IY)                                FL001090
      RETURN                                                        FL001100
 3000 IF(KOUT(IX).GT.1)  RETURN                                     FL001110
      DO 30 IY=2,NYM1                                               FL001120
      I=IY+IX1DY                                                    FL001130
      IE=I+DY                                                       FL001140
      IW=I-DY                                                       FL001150
      RHOU=RHO(I)                                                   FL001160
      IF(U(I).LT.0.0) RHOU=RHO(IE)                                  FL001170
      FLOWE(IY)=RHOU*U(I)*AREAE(IY)                                 FL001180
      RHOU=RHO(IW)                                                  FL001190
      IF(U(IW).LT.0.0)  RHOU=RHO(I)                                 FL001200
   30 FLOWW(IY)=RHOU*U(IW)*AREAE(IY)                                FL001210
      RETURN                                                        FL001220
      END                                                           FL001230
```

```
      SUBROUTINE COEFF(LPHI)                                                CF000010
C-----------------------------------------------------------------------CF000020
CHAPTER 0   0   0   0   0   DECLARATIONS   0   0   0   0   0   0         CF000030
C                                                                         CF000040
      COMMON/COMA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),      CF000050
     1 PP(20),TEM(500),P(414),RHO(500),EMU(500),                          CF000060
     1 DXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),     CF000070
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                            CF000080
     3 A(20),AE(20),AN(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),       CF000090
     4 BSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),             CF000100
     5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),        CF000110
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),         CF000120
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),      CF000130
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),             CF000140
     9 ANUDY(500),AREAH(500),VOL(500),                                    CF000150
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),               CF000160
     1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),          CF000170
     2 RSREF(25),RSSUM(25),TITLE(25)                                      CF000180
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)        CF000190
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),            CF000200
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))                 CF000210
      COMMON/COMB/                                                        CF000220
     1 AK,ARRCON,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,       CF000230
     2 EPSI,EQRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,            CF000240
     3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,          CF000250
     4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,            CF000260
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,       CF000270
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,         CF000280
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,       CF000290
     8 LABPHI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,       CF000300
     9 NXM2,NXYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,          CF000310
     X PRLEXP,PRESS,RELAXP,RF,RFSTM,RSCHEK,RSMAX,R1I,R1O,R2I,R2O,         CF000320
     1 STOICH,TB,TC,TINY,TMAX,TMIN,UB,UC,WMIX                             CF000330
      DIMENSION D(20)                                                     CF000340
C-----------------------------------------------------------------------CF000350
CHAPTER 1 1 1 1 1 1 1 1 1 1     PRELIMINARIES     1 1 1 1 1 1 1 1 1 1 1 1CF000360
C-----------------------------------------------------------------------CF000370
C---------------  DEFINE ARITHMETIC FUNCTION FOR COMBINING               CF000380
C                 APPROPRIATELY CONVECTION AND DIFFUSION CONTRIBUTIONS  CF000390
C                                                                         CF000400
      CONDIF(DIFF,CONV)=AMAX1(DIFF,  DIFF+CONV)                           CF000410
C                                                                         CF000420
      JPHI=LPHI                                                           CF000430
      IF(JPHI.EQ.0)   GO TO 10                                            CF000440
      IF(JPHI.EQ.JU)  GO TO 20                                            CF000450
      IF(JPHI.EQ.JV)  GO TO 30                                            CF000460
      IF(JPHI.EQ.JPP) GO TO 40                                            CF000470
      GO TO 50                                                            CF000480
C                                                                         CF000490
C                 DIFFUSION TERMS FOR CONTINUITY CELLS                    CF000500
C                                                                         CF000510
```

```
   10 DO 150 IY=2,NYM1                                                  CF000530
      I=IY+IX1NY                                                        CF000540
      IW=I-NY                                                           CF000550
      IE=I+NY                                                           CF000560
      IWW=IW-NY                                                         CF000570
      IEE=IE+NY                                                         CF000580
      DIFN(IY)=0.5*(EMU(I+1)+EMU(I))*ANDDY(I)                           CF000590
      IF(IX.EQ.2) GO TO 153                                             CF000600
      DIFW(IY)=0.5*(EMU(IW)+EMU(I))*AEDDX(IW)                           CF000610
      IF(INC.EQ.1) GO TO 154                                            CF000620
      DIFWW(IY)=0.5*(EMU(IWW)+EMU(IW))*AEDDX(IWW)                       CF000630
      DIFNW(IY)=0.5*(EMU(IW+1)+EMU(IW))*ANDDY(IW)                       CF000640
      GO TO 154                                                         CF000650
  153 DIFW(IY)=0.0                                                      CF000660
  154 IF(IX.EQ.NXM1) GO TO 156                                          CF000670
      DIFE(IY)=0.5*(EMU(I)+EMU(IE))*AEDDX(I)                            CF000680
      IF(INC.EQ.-1) GO TO 158                                           CF000690
      DIFEE(IY)=0.5*(EMU(IE)+EMU(IEE))*AEDDX(IE)                        CF000700
      DIFNE(IY)=0.5*(EMU(IE+1)+EMU(IE))*ANDDY(IE)                       CF000710
      GO TO 158                                                         CF000720
  156 DIFE(IY)=0.0                                                      CF000730
  158 CONTINUE                                                          CF000740
      DIFN(IYL)=0.0                                                     CF000750
      DIFNE(IYL)=0.0                                                    CF000760
      DIFN(NYM1)=0.0                                                    CF000770
      DIFNE(NYM1)=0.0                                                   CF000780
      RETURN                                                            CF000790
C-----------------------------------------------------------------------CF000800
CHAPTER 2 2 2 2 2 2 2     COEFFICIENTS FOR U-EQUATION    2 2 2 2 2 2 2 2CF000810
C-----------------------------------------------------------------------CF000820
   20 IF(INC.EQ.-1) GO TO 289                                           CF000830
      CN=FLOWN(IYFM1)+FLOWNE(IYFM1)                                     CF000840
      IF(IXU.EQ.2) CN=CN+FLOWN(IYFM1)                                   CF000850
      IF(IXU.EQ.NXM2) CN=CN+FLOWNE(IYFM1)                               CF000860
      AN(IYFM1)=0.5*AMAX1(0.0,-CN)                                      CF000870
C                                                                       CF000880
      DO 26 IY=IYF,IYL                                                  CF000890
      DN=DIFNE(IY)+DIFN(IY)                                             CF000900
      DE=DIFEE(IY)+DIFE(IY)                                             CF000910
      DW=DIFW(IY)+DIFE(IY)                                              CF000920
      CS=CN                                                             CF000930
      CN=FLOWNE(IY)+FLOWN(IY)                                           CF000940
      CE=FLOWEE(IY)+FLOWE(IY)                                           CF000950
      CW=FLOWW(IY)+FLOWE(IY)                                            CF000960
      IF (IXU.NE.NXM2) GO TO 287                                        CF000970
      CN=CN+FLOWNE(IY)                                                  CF000980
      DN=DN+DIFNE(IY)                                                   CF000990
      CE=FLOWEE(IY)+FLOWEE(IY)                                          CF001000
      DE=0.0                                                            CF001010
      GO TO 286                                                         CF001020
  287 IF (IXU.NE.2) GO TO 286                                           CF001030
      DW=0.0                                                            CF001040
```

```
      CW=FLOWW(IY)+FLOWW(IY)                                          CF001050
      CN=CN+FLOWN(IY)                                                 CF001060
      DN=DN+DIFN(IY)                                                  CF001070
C-------------------  COMBINING DIFFUSION AND CONVECTION CONTRIBUTIONS CF001080
  286 AS(IY)=AN(IY-1)+0.5*CS                                          CF001090
      AN(IY)=0.5*CONDIF(DN,-CN)                                       CF001100
      AE(IY)=0.5*CONDIF(DE,-CE)                                       CF001110
   26 AW(IY)=0.5*CONDIF(DW, CW)                                       CF001120
      GO TO 299                                                       CF001130
C                                                                     CF001140
  289 CN=FLOWNW(IYFM1)+FLOWN(IYFM1)                                   CF001150
      IF(IXU.EQ.2) CN=CN+FLOWNW(IYFM1)                                CF001160
      IF(IXU.EQ.NXM2) CN=CN+FLOWN(IYFM1)                              CF001170
      AN(IYFM1)=0.5*AMAX1(0.0,-CN)                                    CF001180
C                                                                     CF001190
      DO 27 IY=IYF,IYL                                                CF001200
      DN=DIFNW(IY)+DIFN(IY)                                           CF001210
      DE=DIFE(IY)+DIFW(IY)                                            CF001220
      DW=DIFW(IY)+DIFWW(IY)                                           CF001230
      CS=CN                                                           CF001240
      CN=FLOWNW(IY)+FLOWN(IY)                                         CF001250
      CE=FLOWE(IY)+FLOWW(IY)                                          CF001260
      CW=FLOWWW(IY)+FLOWW(IY)                                         CF001270
      IF(IXU.NE.NXM2) GO TO 297                                       CF001280
      CN=CN+FLOWN(IY)                                                 CF001290
      DN=DN+DIFN(IY)                                                  CF001300
      CE=FLOWE(IY)+FLOWE(IY)                                          CF001310
      DE=0.0                                                          CF001320
      GO TO 296                                                       CF001330
  297 IF(IXU.NE.2) GO TO 296                                          CF001340
      DW=0.0                                                          CF001350
      CW=FLOWWW(IY)+FLOWWW(IY)                                        CF001360
      CN=CN+FLOWNW(IY)                                                CF001370
      DN=DN+DIFNW(IY)                                                 CF001380
  296 AS(IY)=AN(IY-1)+0.5*CS                                          CF001390
      AN(IY)=0.5*CONDIF(DN,-CN)                                       CF001400
      AE(IY)=0.5*CONDIF(DE,-CE)                                       CF001410
   27 AW(IY)=0.5*CONDIF(DW, CW)                                       CF001420
C                                                                     CF001430
  299 CALL SOURCE(JU)                                                 CF001440
C                                                                     CF001450
C     IYL BOUNDARY                                                    CF001460
C                                                                     CF001470
      IF (IYL.NE.NYM1) GO TO 1070                                     CF001480
      CALL WALL(NY,STERM,STERM1,0,JP(I)                               CF001490
      SP(IYL)=SP(IYL)-STERM1                                          CF001500
 1070 IF (KTEST.GT.2) CALL TEST(31)                                   CF001510
C                                                                     CF001520
      IYFL=IYF+IYL                                                    CF001530
      IS=IYFM1+IX1NYU                                                 CF001540
      A(IYFM1)=0.0                                                    CF001550
      B(IYFM1)=U(IS)                                                  CF001560
```

```
      DO 290 IY=IYF,IYL                                                 CF001570
      IYM1=IY-1                                                         CF001580
      I=IY+IX1NYU                                                       CF001590
      IP=IYM1+IX2NYU                                                    CF001600
      IEP=IP+NYM2                                                       CF001610
      IE=I+NY                                                           CF001620
      IW=I-NY                                                           CF001630
      C(IY)=SU(IY)+AE(IY)*U(IE)+AW(IY)*U(IW)                            CF001640
      D(IY)=AE(IY)+AW(IY)+AS(IY)+AN(IY)-SP(IY)                          CF001650
      CSNIP(IY)=C(IY)-AREAE(IY)*(P(IP)-P(IEP))                          CF001660
      DSNIP(IY)=D(IY)                                                   CF001670
      ASNIP(IY)=AN(IY)                                                  CF001680
      BSNIP(IY)=AS(IY)                                                  CF001690
      DU(IY)=AREAE(IY)/D(IY)                                            CF001700
      TERM=D(IY)-AS(IY)*A(IYM1)                                         CF001710
      A(IY)=AN(IY)/TERM                                                 CF001720
  290 B(IY)=(C(IY)+B(IYM1)*AS(IY))/TERM                                 CF001730
      IF (ISNIP.EQ.0) RETURN                                            CF001740
      SUM=0.0                                                           CF001750
      DO 291 IY=IYF,IYL                                                 CF001760
      IF (SP(IY).LT.-1.0E08) GO TO 291                                  CF001770
      I=IY+IX1NYU                                                       CF001780
      RS=D(IY)*U(I)-C(IY)-AN(IY)*U(I+1)-AS(IY)*U(I-1)                   CF001790
      SUM=SUM+RS                                                        CF001800
  291 CONTINUE                                                          CF001810
      RSLINE(IXU,JPHI)=SUM/RSREF(JPHI)                                  CF001820
      ARSL(IXU,JPHI)=ABS(RSLINE(IXU,JPHI))                              CF001830
      DO 292 IDASH=IYF,IYL                                              CF001840
      IY=IYFL-IDASH                                                     CF001850
      I=IY+IX1NYU                                                       CF001860
  292 U(I)=A(IY)*U(I+1)+B(IY)                                           CF001870
      RETURN                                                            CF001880
C-----------------------------------------------------------------------CF001890
CHAPTER   3 3 3 3 3 3 3      COEFFICIENTS FOR V-EQUATION   3 3 3 3 3 3  CF001900
C-----------------------------------------------------------------------CF001910
   30 CN=FLOWN(IYFM1)                                                   CF001920
      AN(IYFM1)=AMAX1(0.0,-CN)                                          CF001930
      CN=CN+CN                                                          CF001940
      DO 36 IY=IYF,IYLM1                                                CF001950
      IYP1=IY+1                                                         CF001960
      DN=DIFN(IY)+DIFN(IYP1)                                            CF001970
      DE=DIFE(IY)+DIFE(IYP1)                                            CF001980
      DW=DIFW(IY)+DIFW(IYP1)                                            CF001990
      CS=CN                                                             CF002000
      CN=FLOWN(IY)+FLOWN(IYP1)                                          CF002010
      CE=FLOWE(IY)+FLOWE(IYP1)                                          CF002020
      CW=FLOWW(IY)+FLOWW(IYP1)                                          CF002030
      IF (IY.NE.NYM2) GO TO 387                                         CF002040
      CE=CE+FLOWE(IYP1)                                                 CF002050
      CW=CW+FLOWW(IYP1)                                                 CF002060
      DE=DE+DIFE(IYP1)                                                  CF002070
      DW=DW+DIFW(IYP1)                                                  CF002080
```

```
      CN=FLOWN(IYP1)+FLOWN(IYP1)                                        CF002090
      DN=0.0                                                            CF002100
      GO TO 386                                                         CF002110
  387 IF (IY.NE.2) GO TO 386                                            CF002120
      CE=CE+FLOWE(IY)                                                   CF002130
      CW=CW+FLOWW(IY)                                                   CF002140
      DE=DE+DIFE(IY)                                                    CF002150
      DW=DW+DIFW(IY)                                                    CF002160
C-----------------  COMBINING DIFFUSION AND CONVECTION CONTRIBUTIONS    CF002170
  386 AS(IY)=AN(IY-1)+CS*0.5                                            CF002180
      AN(IY)=0.5*CONDIF(DN,-CN)                                         CF002190
      AE(IY)=0.5*CONDIF(DE,-CE)                                         CF002200
   36 AW(IY)=0.5*CONDIF(DW, CW)                                         CF002210
      CALL SOURCE(JV)                                                   CF002220
C                                                                       CF002230
C     IXL BOUNDARY                                                      CF002240
C                                                                       CF002250
      IF(IX.NE.NXM1)  GO TO 2054                                        CF002260
      DO 2050 IY=IYF,IYLM1                                              CF002270
      CALL WALL(NX,STERM,STERM1,IY,JPHI)                                CF002280
 2050 SP(IY)=SP(IY)-STERM1                                              CF002290
 2054 IF (KTEST.GT.2) CALL TEST(31)                                     CF002300
      IYFL=IYF+IYLM1                                                    CF002310
      IS=IYFM1+IX1NY1                                                   CF002320
      A(IYFM1)=0.0                                                      CF002330
      B(IYFM1)=V(IS)                                                    CF002340
      DV(IYFM1)=0.0                                                     CF002350
      DO 390 IY=IYF,IYLM1                                               CF002360
      IYM1=IY-1                                                         CF002370
      I=IY+IX1NY1                                                       CF002380
      IE=I+NYM1                                                         CF002390
      IW=I-NYM1                                                         CF002400
      IA=IY+IX1NY                                                       CF002410
      C(IY)=SU(IY)+AE(IY)*V(IE)+AW(IY)*V(IW)                            CF002420
      D(IY)=AE(IY)+AW(IY)+AS(IY)+AN(IY)-SP(IY)                          CF002430
      DV(IY)=AREAN(IA)/D(IY)                                            CF002440
      TERM=D(IY)-AS(IY)*A(IYM1)                                         CF002450
      A(IY)=AN(IY)/TERM                                                 CF002460
  390 B(IY)=(C(IY)+B(IYM1)*AS(IY))/TERM                                 CF002470
      SUM=0.0                                                           CF002480
      DO 391 IY=IYF,IYLM1                                               CF002490
      IF (SP(IY) .EQ.-1.0E08) GO TO 391                                 CF002500
      I=IY+IX1NY1                                                       CF002510
      RS=D(IY)*V(I)-C(IY)-AN(IY)*V(I+1)-AS(IY)*V(I-1)                   CF002520
      SUM=SUM+RS                                                        CF002530
  391 CONTINUE                                                          CF002540
      RSLINE(IX,JPHI)=SUM/RSREF(JPHI)                                   CF002550
      ARSL(IX,JPHI)=ABS(RSLINE(IX,JPHI))                                CF002560
      DO 392 IDASH=IYF,IYLM1                                            CF002570
      IY=IYFL-IDASH                                                     CF002580
      I=IY+IX1NY1                                                       CF002590
  392 V(I)=A(IY)*V(I+1)+B(IY)                                           CF002600
```

```
      RETURN                                                            CF002610
C-----------------------------------------------------------------------CF002620
CHAPTER  4 4 4 4 4   COEFFICIENTS FOR PRESSURE-CORRECTION EQUATION   4 4CF002630
C-----------------------------------------------------------------------CF002640
   40 DO 46 IY=IYF,IYL                                                  CF002650
      I=IX1NY+IY                                                        CF002660
      IN=I+1                                                            CF002670
      IL=I+NY                                                           CF002680
      IS=I-1                                                            CF002690
      IW=I-NY                                                           CF002700
      IYM1=IY-1                                                         CF002710
C                                                                       CF002720
      RHOCEL=RHO(IN)                                                    CF002730
      IF(FLOWN(IY).GE.0.0)  RHOCEL=RHO(I)                               CF002740
      AN(IY)=RHOCEL*AREAN(I)*DV(IY)                                     CF002750
C                                                                       CF002760
      RHOCEL=RHO(I)                                                     CF002770
      IF(FLOWN(IYM1).GE.0.0)  RHOCEL=RHO(IS)                            CF002780
      AS(IY)=RHOCEL*AREAN(IS)*DV(IYM1)                                  CF002790
C                                                                       CF002800
      IF (INC.EQ.-1) GO TO 41                                           CF002810
C                                                                       CF002820
      AW(IY)=0.0                                                        CF002830
      RHOCEL=RHO(IE)                                                    CF002840
      IF(FLOWE(IY).GE.0.0)  RHOCEL=RHO(I)                               CF002850
      AE(IY)=RHOCEL*AREAE(IY)*DU(IY)                                    CF002860
C                                                                       CF002870
      GO TO 46                                                          CF002880
C                                                                       CF002890
   41 AE(IY)=0.0                                                        CF002900
      RHOCEL=RHO(I)                                                     CF002910
      IF (FLOWW(IY).GE.0.0) RHOCEL=RHO(IW)                              CF002920
      AW(IY)=RHOCEL*AREAE(IY)*DU(IY)                                    CF002930
C                                                                       CF002940
46    CONTINUE                                                          CF002950
C                                                                       CF002960
      CALL SOURCE(JPP)                                                  CF002970
C                                                                       CF002980
                                    IF (KTEST.GT.2) CALL TEST(31)       CF002990
      IYFL=IYF+IYL                                                      CF003000
      A(IYFM1)=0.0                                                      CF003010
      B(IYFM1)=0.0                                                      CF003020
      PP(IYLP1)=0.0                                                     CF003030
      DO 490 IY=IYF,IYL                                                 CF003040
      IYM1=IY-1                                                         CF003050
      C(IY)=SU(IY)                                                      CF003060
      D(IY)=AE(IY)+AW(IY)+AS(IY)+AN(IY)-SP(IY)                          CF003070
      TERM=D(IY)-AS(IY)*A(IYM1)                                         CF003080
      A(IY)=AN(IY)/TERM                                                 CF003090
  490 B(IY)=(C(IY)+B(IYM1)*AS(IY))/TERM                                 CF003100
      DO 492 IDASH=IYF,IYL                                              CF003110
      IY=IYFL-IDASH                                                     CF003120
```

```
  492 PP(IY)=A(IY)*PP(IY+1)+B(IY)                                        CF003130
      RETURN                                                             CF003140
C ------------------------------------------------------------------     CF003150
CHAPTER  5  5  5  5  PHI EQUATION  5  5  5  5  5  5  5  5              CF003160
C ------------------------------------------------------------------     CF003170
50    RPREFF=1./PREFF (JPHI)                                             CF003180
      AN(IYFM1)=AMAX1(0.0,-FLOWN(IYFM1))                                 CF003190
      DO 56 IY=IYF,IYL                                                   CF003200
C------------------  COMBINING DIFFUSION AND CONVECTION CONTRIBUTIONS    CF003210
      AS(IY)=AN(IY-1)+FLOWN(IY-1)                                        CF003220
      AN(IY)=CONDIF(DIFN(IY)*RPREFF,-FLOWN(IY))                          CF003230
      AE(IY)=CONDIF(DIFE(IY)*RPREFF,-FLOWE(IY))                          CF003240
   56 AW(IY)=CONDIF(DIFW(IY)*RPREFF, FLOWW(IY))                          CF003250
C                                                                        CF003260
      CALL SOURCE(JPHI)                                                  CF003270
C                                                                        CF003280
      IF (KTEST.GT.2) CALL TEST(31)                                      CF003290
C                                                                        CF003300
      IYFL=IYF+IYL                                                       CF003310
      ICONST=IXIY(JPHI)+IZERO(JPHI)                                      CF003320
      IS=IYFM1+ICONST                                                    CF003330
      A(IYFM1)=0.0                                                       CF003340
      B(IYFM1)=F(IS)                                                     CF003350
      DO 590 IY=IYF,IYL                                                  CF003360
      IYM1=IY-1                                                          CF003370
      I=IY+ICONST                                                        CF003380
      IE=I+NY                                                            CF003390
      IW=I-NY                                                            CF003400
      C(IY)=SU(IY)+AE(IY)*F(IE)+AW(IY)*F(IW)                             CF003410
      D(IY)=AE(IY)+AW(IY)+AS(IY)+AN(IY)-SP(IY)                           CF003420
      TERM=D(IY)-AS(IY)*A(IYM1)                                          CF003430
      A(IY)=AN(IY)/TERM                                                  CF003440
  590 B(IY)=(C(IY)+B(IYM1)*AS(IY))/TERM                                  CF003450
      SUM=0.0                                                            CF003460
      DO 591 IY=IYF,IYL                                                  CF003470
      IF (SP(IY).LT.-1.0E08) GO TO 591                                   CF003480
      I=IY+ICONST                                                        CF003490
      RS=D(IY)*F(I)-C(IY)-AN(IY)*F(I+1)-AS(IY)*F(I-1)                    CF003500
      SUM=SUM+RS                                                         CF003510
  591 CONTINUE                                                           CF003520
      RSLINE(IX,JPHI)=SUM/RSREF(JPHI)                                    CF003530
      ARSL(IX,JPHI)=ABS(RSLINE(IX,JPHI))                                 CF003540
      DO 592 IDASH=IYF,IYL                                               CF003550
      IY=IYFL-IDASH                                                      CF003560
      I=IY+ICONST                                                        CF003570
  592 F(I)=A(IY)*F(I+1)+B(IY)                                            CF003580
      RETURN                                                             CF003590
      END                                                                CF003600
```

```
      SUBROUTINE TLST(KGOTO)                                                TE000020
      COMMON/COMA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),        TE000030
     1 FP(20),TLM(500),P(414),RHO(500),EMU(500),                            TE000040
     1 RXG(25),RXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),       TE000050
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                              TE000060
     3 A(20),E(20),AH(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),          TE000070
     4 CSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),               TE000080
     5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),          TE000090
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),           TE000100
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),        TE000110
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),               TE000120
     9 ANDLY(500),AREAN(500),VOL(500),                                      TE000130
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),                 TE000140
     1 TEW(25),TLAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),            TE000150
     2 RSPLOT(25),RSSUM(25),TITLE(25)                                       TE000160
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)          TE000170
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),              TE000180
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))                   TE000190
      COMMON/COMB/                                                          TE000200
     1 AK,ARROW,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,          TE000210
     2 EPST,ERRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,              TE000220
     3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,            TE000230
     4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,              TE000240
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,         TE000250
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,           TE000260
     7 JS1,JS2,JTEM,JU,JV,KASL,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,         TE000270
     8 LABPHI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,         TE000280
     9 NXM2,NXYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,           TE000290
     X PREEXP,PRESS,RELAXP,RF,RFSTM,RSCHEK,RSMAX,R1I,R1O,R2I,R2O,           TE000300
     1 STOICH,TB,TC,TINY,TMAX,TMIN,UB,UC,WMIX                               TE000310
C-----------------------------------------------------------------------TE000320
CHAPTER 1  1   1   1   PRINT-OUTS FOR LEVEL 1 ONWARDS        1   1   1   TE000330
C                                                                       TE000340
C--------------------------------  GEOMETRICAL QUANTITES RELATED TO GRIDTE000350
      IF (KGOTO.NE.11) GO TO 3000                                       TE000360
C                                                                       TE000370
      WRITE(6,200) KTEST                                                TE000380
  200 FORMAT(/1X,26HDIAGNOSING PRINT-OUT LEVEL,I4,2X,30(1H-))           TE000390
      WRITE(6,201) (K,X(K),DXG(K),SXG(K),K=1,NX)                        TE000400
  201 FORMAT(/1X,2HIX,1X,10H          X,10H        DXG,10H        SXG/   TE000410
     1(1X,I2,1X,1P3E10.2))                                              TE000420
      WRITE(6,202) (K,XU(K),DXU(K),SXU(K),K=1,NX)                       TE000430
  202 FORMAT(/1X,2HIX,1X,10H         XU,10H        DXU,10H        SXU    TE000440
     1/(1X,I2,1X,1P3E10.2))                                             TE000450
      WRITE(6,203) (K,Y(K),R(K),DYG(K),SYG(K),AREAE(K),K=1,NY)          TE000460
203   FORMAT(/1X,2HIY,1X,10H          Y,10H          R,10H        DYG,   TE000470
     1 10H        SYG,10H     AREAE/(1X,I2,1X,1P5E10.2))                TE000480
      WRITE(6,204) (K,YV(K),RV(K),RVCB(K),DYV(K),SYV(K),K=1,NY)         TE000490
204   FORMAT(/1X,2HIY,1X,10H         YV,10H         RV,10H       RVCB,   TE000500
     1 10H        DYV,10H        SYV/                                   TE000510
     2(1X,I2,1X,1P5E10.2))                                              TE000520
```

```
      K1=1                                                              TE000530
      K2=MIN0(IX,10)                                                    TE000540
  208 WRITE (6,205) (K,K=K1,K2)                                         TE000550
  205 FORMAT(/1X,5HAREA//4X,3HIX=,10I10/1X,2HIY)                        TE000560
      DO 206 IY=1,NY                                                    TE000570
      K3=IY+(K1-1)*NY                                                   TE000580
      K4=IY+(K2-1)*NY                                                   TE000590
  206 WRITE(6,207) IY,(AREA(K),K=K3,K4,NY)                              TE000600
  207 FORMAT(1X,I2,4X,1P10E10.2)                                        TE000610
      IF (K2.EQ.IX) RETURN                                              TE000620
      K1=K2+1                                                           TE000630
      K2=MIN0(K2+10,IX)                                                 TE000640
      GO TO 208                                                         TE000650
      RETURN                                                            TE000660
C------------------------------------------------ VARIABLE INFORMATION  TE000670
 3000 IF (KGO10.NE.12) GO TO 8000                                       TE000680
C                                                                       TE000690
      WRITE(6,300)                                                      TE000700
  300 FORMAT(//1X,30HDEPENDENT VARIABLE INFORMATION,20(1H-)/)           TE000710
      WRITE(6,301) NSOLVE,(TITLE(K),K=1,NSOLVE)                         TE000720
  301 FORMAT(/1X,31HNSOLVE =,I4,1X,5(1H-),10(A4,1H,,1X))                TE000730
      IF(KSOLVE(JPP).EQ.0) GO TO 38                                     TE000740
      WRITE(6,302)                                                      TE000750
  302 FORMAT(1X,14X,44HPRESSURE CORRECTION EQUATION IS ALSO SOLVED.)     TE000760
   38 WRITE(6,303)                                                      TE000770
  303 FORMAT(/1X,4H J  ,4HJPHI,8H  KSOLVE,                              TE000780
     1 8H  IZERO,8H   ILAST,6H     IEW)                                 TE000790
      WRITE(6,304) (K,TITLE(K),KSOLVE(K),                               TE000800
     1 IZERO(K),ILAST(K),IEW(K),K=1,JLAST)                              TE000810
  304 FORMAT (1X,I2,2X,A4,4I8)                                          TE000820
      RETURN                                                            TE000830
C-------------------------------------------------------------------    TE000840
CHAPTER 2   2   2   2   2    PRINT-OUTS FOR LEVEL 2 ONWARDS  2   2   2   TE000850
C                                                                       TE000860
C------STAGGERED VELOCITIES AND THEIR RESIDUAL SOURCES ON TDMA LINE     TE000870
 8000 IF (KGO10.NE.21) GO TO 10000                                      TE000880
C                                                                       TE000890
      IF(KTEST.GT.2) GO TO 804                                          TE000900
      IF(LABPHI.EQ.1) WRITE(6,803 )IX,KOUNT(IX)                         TE000910
      IF(LABPHI.EQ.2.AND.(IXU.EQ.NXM1.OR.IXU.EQ.1)) WRITE(6, 803)       TE000920
     1 IX,KOUNT(IX)                                                     TE000930
803   FORMAT(/1X,53(1H-),4H IX=,I2,12H, KOUNT(IX)=,I3)                  TE000940
804   SYMBOL=1H                                                         TE000950
      IF(LABPHI.GT.JV) SYMBOL=1H                                        TE000960
      ICONST=IXIY(LABPHI)+IZERO(LABPHI)                                 TE000970
      K1=IYF(1)+ICONST                                                  TE000980
      K2=IYL(1)+ICONST                                                  TE000990
      IF(LABPHI.EQ.JV) K2=IYL+ICONST                                    TE001000
      IF(LABPHI.EQ.JU) GO TO 805                                        TE001010
      WRITE(6,870) IX,SYMBOL,TITLE(LABPHI),(F(K),K=K1,K2)               TE001020
      IF(LABPHI.GT.NSOLVE) GO TO 806                                    TE001030
800   FORMAT(/1X,3HIX=,I2,1H,,1X,A1,11H VALUES OF ,A4,1H=,1P5E10.2,     TE001040
```

```
     1 5(/1X,,4X,1P5E10.2))                                                  TE001050
       WRITE(6,801) TITLE(LABPHI),IX,RSLINE(IX,LABPHI)                       TE001060
       GO TO 806                                                             TE001070
  805 WRITE(6,810)IXU,SYMBOL,TITLE(LABPHI),(F(K),K=K1,K2)                   TE001080
       WRITE(6,801)TITLE(LABPHI),IXU,RSLINE(IXU,LABPHI)                      TE001090
  806 CONTINUE                                                              TE001100
801    FORMAT(1X,34HALGEBRAIC SUM OF RESIDUAL SOURCES OF  ,A4,7H AT IX=,     TE001110
      1 I2,9H  IS,10X,1PE10.2)                                              TE001120
       RETURN                                                               TE001130
C----------   LAB-PRESSURE-CORRECTION QUANTITIES                            TE001140
10000 IF (KGO10.NE.2P) GO TO 11000                                          TE001150
C                                                                           TE001160
       WRITE(6,1001) IXU,FLOWUP,FLOWST                                      TE001170
1000   FORMAT(/1X,5HIX=,I2,5H.....,7HFLOWUP,,7HFLOWST,,                     TE001180
      1 1PE10.3)                                                            TE001190
       K1=IYFM1+IX1NYH                                                      TE001200
       K2=IYLP1+IX1NYH                                                      TE001210
       WRITE(6,1001) (U(K),K=K1,K2)                                         TE001220
1001   FORMAT(1X,23HADJUST(1)       U(IYFM1-IYLP1),1P5E10.2,                TE001230
      1 5(/1X,,4X,1P5E10.2))                                                TE001240
       RETURN                                                               TE001250
C-------------------------------------   P=CORRECTION QUANTITIES             TE001260
11000 IF (KGO10.NE.23) GO TO 12000                                          TE001270
C                                                                           TE001280
       WRITE(6,1093)              IX,RSLINE(IX,JPP)                         TE001290
1093   FORMAT(/1X,42HALGEBRAIC SUM OF ERROR MASS SOURCES AT IX=,I3,          TE001300
      1 5H   IS,14X,1PE10.2)                                                TE001310
       WRITE(6,1090) IX,(PP(K),K=IYF,IYL)                                   TE001320
1090   FORMAT(/1X,5HIX=,I2,2X,15HPP(IYF TO IYL) ,5X,1P5E10.2,               TE001330
      1 5(/1X,,4X,1P5E10.2))                                                TE001340
       K1=IYFM1+IX1NY(JU)                                                   TE001350
       K2=IYLP1+IX1NY(JU)                                                   TE001360
       WRITE(6,1191) IXU,(U(K),K=K1,K2)                                     TE001370
1091   FORMAT(1X,5HIX=,I2,2X,24HPP C. U(IYFM1 TO IYLP1) ,1P5E10.2,          TE001380
      1 5(/1X,,4X,1P5E10.2))                                                TE001390
       K1=IYFM1+IX1NY(JV)                                                   TE001400
       K2=IYL+IX1NY(JV)                                                     TE001410
       WRITE(6,1092) IX,(V(K),K=K1,K2)                                      TE001420
1092   FORMAT(1X,5HIX=,I2,2X,18HPP C. V(IYFM1-IYL),1P5E10.2,                TE001430
      1 5(/1X,,4X,1P5E10.2))                                                TE001440
       RETURN                                                               TE001450
C                                                                           TE001460
12000 IF (KGO10.NE.24) GO TO 2000                                           TE001470
       WRITE (6,1200) DP                                                    TE001480
 1200  FORMAT(/1X,29HADJUST(3), MEAN-P CORRECTION=,1PE10.2)                 TE001490
       K1=2                                                                 TE001500
       K2=(J+10(IX-M1,11)                                                   TE001510
 1208  WRITE(6,1205) (K,K=K1,K2)                                            TE001520
 1205  FORMAT(/1X,25HPRESSURES AFTER ADJUST(3)//4X,3HIX=,10I10/             TE001530
      1 1X,2HIY)                                                            TE001540
       DO 1206 IY=1,NYM2                                                    TE001550
       I1=NY-IY+1                                                           TE001560
```

```
      K3=I7+(I 1-2)*NYM2-1                                                  TE001570
      K4=I1+(I 2-2)*NYM2-1                                                  TE001580
 1200 WRITE(6,2017) IY,(P(K),K=K3,K4,NYM2)                                  TE001590
      IF(K2.E .IX-1) RETURN                                                 TE001600
      K1=K2+1                                                               TE001610
      K2=MIN0(K2+10,NXM1)                                                   TE001620
      GO TO 1200                                                            TE001630
      RETURN                                                                TE001640
C-------------------------------------------------------------------------TE001650
CHAPTER 3   3   3   3   PRINT-OUTS FOR LEVEL 3   ONWARDS   3   3   3   3   TE001660
C                                                                           TE001670
C---------------    COEFFICIENTS OF FINITE-DIFFERENCE EQUATIONS             TE001680
 2000 IF (KGOTO.NE.31) GO TO 4000                                           TE001690
C                                                                           TE001700
      IF(LABPHI.EQ.1) GO TO 2022                                            TE001710
      WRITE(6,2020) TITLE(LABPHI),IX                                        TE001720
      GO TO 2023                                                            TE001730
 2022 WRITE(6,2020) TITLE(LABPHI),IXU                                       TE001740
 2023 CONTINUE                                                              TE001750
 2020 FORMAT(//1X,16HCOEFFICIENTS OF ,A4,2X,17HEQUATION FOR IX =,I4,2X,2TE001760
     1O(1H-)//1X,2HIY,2X,10H         AN,10H         AS,10H         AE,     TE001770
     110H         AW,10H         SU,10H         SP)                       TE001780
      K2=IYL                                                                TE001790
      IF (LABPHI.EQ.2) K2=IYLM1                                             TE001800
      WRITE (6,2021)(K,AN(K),AS(K),AE(K),AW(K),SU(K),SP(K),K=IYF,K2)        TE001810
 2021 FORMAT(1X,I2,2X,1P6E10.2)                                             TE001820
      RETURN                                                                TE001830
C                                                                           TE001840
C     MASS FLOW RATES                                                       TE001850
C                                                                           TE001860
 4000 IF (KGOTO.NE.40) GO TO 4100                                           TE001870
      IF(IHC.EQ.-1) GO TO 401                                               TE001880
      WRITE(6,400)                                                          TE001890
      WRITE(6,409) (K,FLOWN(K),FLOWE(K),FLOWW(K),FLOWNE(K),FLOWNW(K),      TE001900
     1K=2,NY)                                                               TE001910
  400 FORMAT(//1X,2HIY,2X,10H      FLOWN,10H      FLOWE,10H      FLOWW,     TE001920
     110H     FLOWNE,10H     FLOWNW/)                                       TE001930
  409 FORMAT(1X,I2,2X,1P5E10.2)                                             TE001940
      GO TO 402                                                             TE001950
  401 WRITE(6,403)                                                          TE001960
      WRITE(6,409) (K,FLOWNW(K),FLOWW(K),FLOWSW(K),FLOWE(K),FLOWN(K),      TE001970
     1 K=2,NY)                                                              TE001980
  402 CONTINUE                                                              TE001990
  403 FORMAT(//1X,2HIY,2X,10H     FLOWNW,10H      FLOWW,10H     FLOWSW,     TE002000
     1 10H      FLOWE,10H      FLOWN/)                                       TE002010
      RETURN                                                                TE002020
C                                                                           TE002030
C------DIFFUSION TERMS.                                                    TE002040
C                                                                           TE002050
 4100 IF(KGOTO.NE.41) RETURN                                                TE002060
      WRITE(6,4130)IX,KOUNT(IX)                                             TE002070
4130  FORMAT(//1X,53(1H-),4H IX=,I2,12H, KOUNT(IX)=,I5)                     TE002080
```

```
      IF(IBC.LO.-1) GO TO 411                                                  TE002090
      WRITE (6,410)                                                            TE002100
      WRITE (6,409) (K,DIFN(K),DIFE(K),DIFW(K),DIFEE(K),DIFNE(K),              TE002110
     1 K=2,NY)                                                                 TE002120
  410 FORMAT(//1X,2HJY,2X,10H      DIFN,10H      DIFE,10H      DIFW,           TE002130
     1 10H      DIFEE,10H      DIFNE/)                                        TE002140
      GO TO 412                                                                TE002150
  411 WRITE(6,413)                                                             TE002160
      WRITE(6,409) (K,DIFNW(K),DIFW(K),DIFWW(K),DIFE(K),DIFN(K),               TE002170
     1 K=2,NY)                                                                 TE002180
  412 CONTINUE                                                                 TE002190
  413 FORMAT(//1X,2HJY,2X,10H      DIFNW,10H      DIFW,10H      DIFWW,         TE002200
     1 10H      DIFE,10H      DIFN/)                                          TE002210
      RETURN                                                                   TE002220
      END                                                                      TE002230
```

```
                                                                        RE000010
      SUBROUTINE REACT                                                  RE000020
      LOGICAL CONVG                                                     RE000030
      DOUBLE PRECISION A,X,Y                                            RE000040
      COMMON /INDEX/ IDCO,IDCO2,IDF,IDH,IDH2,IDH2O,IDO,IDOH,IDO2,IDN,   RE000050
     1 IDNO,IDNO2,IDN2,IDN2O,IEQUIL,IHCPS,IFR,JJ,KNTCS,NA,NLM,          RE000060
     2 NS,NSE1,NSE2,NSK,NSM,NS1,NS2,ID(4,15)                            RE000070
     3/PARAMS/ CONVG,EMV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNYRE000080
     5/SPECES/ASUB(20,3),CPSUM,HSUM,H0(14),SMW(14),S0(14),S1(14),       RE000090
     6 S2(14),Z(2,7,14)                                                 RE000100
     7/EQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,       RE000110
     8 AS1(4,7,2),HDIV,HMAX,HMIN,PEXP(7)                                RE000120
     9/REACTS/BX(15),BX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)        RE000130
      COMMON/ELMNTS/ATOM(3,7),B0(7)                                     RE000140
     1 /STOCHS/ AL(7,14)                                                RE000150
     2 /MATRIX/ A(14,15),X(15),Y(15)                                    RE000160
      DIMENSION DATA(12),AT(4),B(4)                                     RE000170
C-------------------------------------------------------------------    RE000180
CHAPTER  1  1  1  1  1  1  1  1   PRELIMINARIES   1  1  1  1  1  1  1    RE111191
C-------------------------------------------------------------------    RE000200
      DATA ELEM/4HELEM/                                                 RE000210
      DATA REVRS/4HREVE/,THIRD/4HM   /                                  RE000220
      DATA THERM/4HTHER/,AMCH/4HMECH/,BLANK/4H    /                     RE000230
      DATA TENLN/2.302585/,XMAX/0.001/,XMIN/0.000333333/                RE000240
  900 READ (5,901) (DATA(I),I=1,12)                                     RE000250
  901 FORMAT (12A4)                                                     RE000260
      IF (DATA(1).EQ.BLANK) GO TO 900                                   RE000270
      IF (DATA(1).EQ.ELEM) GO TO 10                                     RE000280
      IF (DATA(1).EQ.THRM) GO TO 20                                     RE000290
      IF (KNTCS.EQ.0) RETURN                                            RE000300
      IF (DATA(1).EQ.AMCH) GO TO 30                                     RE000310
C-------------------------------------------------------------------    RE000320
CHAPTER  2  2  2  2  2  2  2  2   ELEMENT DATA    2  2  2  2  2  2  2    RE000330
C-------------------------------------------------------------------    RE000340
   10 NLM=1                                                             RE000350
   11 READ (5,1,0) (ATOM(K,NLM),K=1,2)                                  RE000360
  150 FORMAT (A2,7X,F10.6)                                              RE000370
      IF (ATOM(1,NLM).EQ.BLANK) GO TO 12                                RE000380
      NLM=NLM+1                                                         RE000390
      GO TO 11                                                          RE000400
   12 NLM=NLM-1                                                         RE000410
      GO TO 900                                                         RE000420
C-------------------------------------------------------------------    RE000430
CHAPTER  3  3  3  3  3  3  3   THERMODYNAMIC DATA    3  3  3  3  3  3  3RE000440
C-------------------------------------------------------------------    RE000450
   20 NS=1                                                              RE000460
   21 READ (5,220) (DATA(I),I=1,3),(AT(J),B(J),J=1,4),T1,T2,NCD         RE000470
  220 FORMAT (3A4,13X,4(A2,F3.0),1X,2F10.3,I15)                         RE000480
      IF (DATA(1).EQ.BLANK) GO TO 26                                    RE000490
      READ(5,222) (Z(1,J,NS),J=1,5),NCD                                 RE000500
  222 FORMAT(5E15.8,I5)                                                 RE000510
      READ(5,222) (Z(1,J,NS),J=6,7),(Z(2,K,NS),K=1,3),NCD               RE000520
```

```
      READ(5,223) (Z(2,J,NS),J=4,7),NCD                                  RE000530
  223 FORMAT(4E15.8,T20)                                                 RE000540
      DO 22 L=1,NLM                                                      RE000550
   22 AL(L,NS)=0.0                                                       RE000560
      SUM=0.0                                                            RE000570
      DO 24 K=1,4                                                        RE000580
      IF (B(K).EQ.0.) GO TO 24                                           RE000590
      DO 23 L=1,NLM                                                      RE000600
      IF (ATOM(1,L).NE.AT(K)) GO TO 23                                   RE000610
      AL(L,NS)=AL(L,NS)+B(K)                                             RE000620
      SUM=SUM+ATOM(2,L)*B(K)                                             RE000630
   23 CONTINUE                                                           RE000640
   24 CONTINUE                                                           RE000650
      SMW(NS)=SUM                                                        RE000660
      DO 25 I=1,3                                                        RE000670
   25 ASUB(NS,I)=DATA(I)                                                 RE000680
      NS=NS+1                                                            RE000690
      GO TO 21                                                           RE000700
   26 NS=NS-1                                                            RE000710
      NSM=NS+1                                                           RE000720
      NA=NS+1                                                            RE000730
      DO 27 I=1,NS                                                       RE000740
      RSMW=1.0/SMW(I)                                                    RE000750
      DO 27 J=1,7                                                        RE000760
      DO 27 K=1,2                                                        RE000770
   27 Z(K,J,I)=Z(K,J,I)*RSMW                                             RE000780
      GO TO 900                                                          RE000790
C-----------------------------------------------------------------------RE000800
CHAPTER  4  4  4  4  4  4  REACTION MECHANISM DATA  4  4  4  4  4  4  4 RE000810
C-----------------------------------------------------------------------RE000820
   30 JJ=1                                                               RE000830
   31 READ (5,330) (DATA(I),I=1,12),BX(JJ),TEN(JJ),TACT(JJ),DT1,DT2      RE000840
  330 FORMAT (12A4,3F8.3,2A4)                                           RE000850
      IF (DATA(1).EQ.BLANK) GO TO 354                                    RE000860
      IF (DT1.EC.RVRS) GO TO 32                                          RE000870
      J=JJ-1                                                             RE000880
      BX2(J)=BX(JJ)                                                      RE000890
      TEN2(J)=TEN(JJ)                                                    RE000900
      TACT2(J)=TACT(JJ)                                                  RE000910
      BX2(J)=10.**BX2(J)                                                 RE000920
      GO TO 3.                                                           RE000930
   32 BX(JJ)=10.0**BX(JJ)                                                RE000940
      DO 33 I=1,4                                                        RE000950
   33 ID(I,JJ)=0                                                         RE000960
      NC=1                                                               RE000970
      DO 3. M=1,6                                                        RE000980
      K=M*2-1                                                            RE000990
      IF (DATA(K).EQ.BLANK) GO TO 38                                     RE001000
      IF (DATA(K).NE.THIRD) GO TO 34                                     RE001010
      DATA(K)=BLANK                                                      RE001020
      GO TO 3.                                                           RE001030
   34 DO 35 I=1,NS                                                       RE001040
```

```
      IF (DATA(K).NE.ASUB(I,1)) GO TO 35                                RE001050
      IF (DATA(K+1).NE.ASUB(I,2)) GO TO 35                              RE001060
      II=I                                                              RE001070
      GO TO 36                                                          RE001080
   35 CONTINUE                                                          RE001090
   36 IF (K.GT.4) GO TO 37                                              RE001100
      ID(ID,JJ)=II                                                      RE001110
      ID=ID+1                                                           RE001120
      GO TO 38                                                          RE001130
   37 IF (ID.LT.2) ID=3                                                 RE001140
      ID(ID,JJ)=II                                                      RE001150
      ID=ID+1                                                           RE001160
   38 DX=(XMAX-XMIN)*7.142857E-2                                        RE001170
      SUMX=0.0                                                          RE001180
      SUMY=0.0                                                          RE001190
      IDCPS=3                                                           RE001200
      NS1=1                                                             RE001210
      NS2=NS                                                            RE001220
      DO 351 I=1,15                                                     RE001230
      X(I)=XMIN+DX*FLOAT(I-1)                                           RE001240
      SUMX=SUMX+X(I)                                                    RE001250
      TKINV=X(I)                                                        RE001260
      TK=1.0/TKINV                                                      RE001270
      TLN=ALOG(TK)                                                      RE001280
      CALL IDCPS                                                        RE001290
      SUM1=0.0                                                          RE001300
      DO 350 ID=1,4                                                     RE001310
      K=ID(ID,JJ)                                                       RE001320
      IF (K.EQ.0) GO TO 350                                             RE001330
      DF=(HO(K)-SO(K))*SMW(K)                                           RE001340
      IF (ID.LT.3) SUM1=SUM1+DF                                         RE001350
      IF (ID.GE.3) SUM1=SUM1-DF                                         RE001360
  350 CONTINUE                                                          RE001370
      SUM1=EXP(SUM1)                                                    RE001380
      TM1=1.0                                                           RE001390
      IF (ID(2,JJ).EQ.0) TM1=0.082057*TK                                RE001400
      IF (ID(4,JJ).EQ.0) TM1=1.0/(0.082057*TK)                          RE001410
      AK=BX(JJ)                                                         RE001420
      IF (TEN(JJ).NE.0.0) AK=AK*TK**TEN(JJ)                             RE001430
      IF (TACT(JJ).NE.0.0) AK=AK*EXP(-TACT(JJ)*TKINV)                   RE001440
      AK=AK*TM1/SUM1                                                    RE001450
      Y(I)=ALOG(AK)                                                     RE001460
  351 SUMY=SUMY+Y(I)                                                    RE001470
      XBAR=SUMX*6.666667E-2                                             RE001480
      YBAR=SUMY*6.666667E-2                                             RE001490
      SUMX=0.0                                                          RE001500
      SUM1=0.0                                                          RE001510
      SUMY=0.0                                                          RE001520
      DO 352 I=1,15                                                     RE001530
      SUMX=SUMX+Y(I)*(X(I)-XBAR)                                        RE001540
      SUM1=SUM1+(X(I)-XBAR)**2                                          RE001550
  352 SUMY=SUMY+(Y(I)-YBAR)**2                                          RE001560
```

```
      TF(J2(JJ)=0.0                                                    RE001570
      TACT2(JJ)=-SUMX/SUM1                                             RE001580
      BX2(JJ)=(YBAR+TACT2(JJ)*XBAR)/TENLN                              RE001590
      SUMX=0.1                                                         RE001600
      DO 355 I=1,15                                                    RE001610
  355 SUMX=SUMX+(Y(I)+TACT2(JJ)*X(I)-TENLN*BX2(JJ))**2                 RE001620
      SUMY=SQRT(1.-SUMX/SUMY)                                          RE001630
      SUMX=SQRT(SUMY*7.142857E-2)                                      RE001640
      BX2(JJ)=10.**BX2(JJ)                                             RE001650
      JJ=JJ+1                                                          RE001660
      GO TO 31                                                         RE001670
  354 JJ=JJ-1                                                          RE001680
      RETURN                                                           RE001690
      END                                                              RE001700
```

```
                                                                        HCPS0010
      SUBROUTINE HCPS                                                   HCPS0020
      LOGICAL CONVG                                                     HCPS0030
      COMMON /IPOCX/ IOCO,IOCO2,IOF,IOH,IOH2,IOH20,IOO,IOOH,IOO2,IOH,   HCPS0040
     1 IOOH,IOH2,IOH2,IOH20,IEQUIL,IHCPS,IPR,JJ,KNTCS,NA,NLM,           HCPS0050
     2 NS,NSC1,NSC2,NSK,NSM,NS1,NS2,ID(4,15)                            HCPS0060
     3/PARAM/ CONVG,ERV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLN,TNYHCPS0070
     5/PROCESS/A(20,3),CPSUM,HSUM,H0(14),SMW(14),S0(14),S1(14),         HCPS0080
     6 Z(16),Z(2,7,14)                                                  HCPS0090
     7/EQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,       HCPS0100
     8 AS1(4,7,2),HDIV,HMAX,HMIN,PEXP(7)                               HCPS0110
     9/RCAUTS/DX(15),DX2(15),TACT(15),TACT2(15),TFN(15),TEN2(15)        HCPS0120
C-------------------------------------------------------------------- HCPS0130
CHAPTER  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1   HCPS0140
C-------------------------------------------------------------------- HCPS0150
      K=1                                                               HCPS0160
      IF (TK.LT.1000.) K=2                                              HCPS0170
      TKINV=1.0/TK                                                      HCPS0180
      TK3=TK*TK                                                         HCPS0190
      TK4=TK3*TK                                                        HCPS0200
      TK5=TK4*TK                                                        HCPS0210
      TM2=0.5*TI                                                        HCPS0220
      TM3=0.333333*TK3                                                  HCPS0230
      TM4=0.25*TK4                                                      HCPS0240
      TM5=0.2*TK5                                                       HCPS0250
      IF (IHCPS-2) 100,200,300                                          HCPS0260
  100 HSUM=0.0                                                          HCPS0270
      DO 10 IS=NS1,NS2                                                  HCPS0280
      H0(IS)=TM5*Z(K,5,IS)+TM4*Z(K,4,IS)+TM3*Z(K,3,IS)+TM2*Z(K,2,IS)+   HCPS0290
     1 Z(K,1,IS)+Z(K,6,IS)*TKINV                                        HCPS0300
   10 HSUM=HSUM+H0(IS)*S2(IS)                                           HCPS0310
      RETURN                                                            HCPS0320
C-------------------------------------------------------------------- HCPS0330
CHAPTER  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2   HCPS0340
C-------------------------------------------------------------------- HCPS0350
  200 HSUM=0.0                                                          HCPS0360
      CPSUM=0.0                                                         HCPS0370
      DO 20 IS=NS1,NS2                                                  HCPS0380
      ZK5I=Z(K,5,IS)                                                    HCPS0390
      ZK4I=Z(K,4,IS)                                                    HCPS0400
      ZK3I=Z(K,3,IS)                                                    HCPS0410
      ZK2I=Z(K,2,IS)                                                    HCPS0420
      ZK1I=Z(K,1,IS)                                                    HCPS0430
      H0(IS)=TM5*ZK5I+TM4*ZK4I+TM3*ZK3I+TM2*ZK2I+ZK1I+Z(K,6,IS)*TKINV   HCPS0440
      CPSUM=(TK5*ZK5I+TK4*ZK4I+TK3*ZK3I+TK*ZK2I+ZK1I)*S2(IS)+CPSUM      HCPS0450
   20 HSUM=HSUM+H0(IS)*S2(IS)                                           HCPS0460
      RETURN                                                            HCPS0470
C-------------------------------------------------------------------- HCPS0480
CHAPTER  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3  3   HCPS0490
C-------------------------------------------------------------------- HCPS0500
  300 TM3=0.5*TK3                                                       HCPS0510
      TM4=0.333333*TM4                                                  HCPS0520
```

```
      TK5=0.25*TK5                                                          HCPS0530
      DO 30 I=IS1,IS2                                                       HCPS0540
      ZK5I=Z(K,5,I)                                                         HCPS0550
      ZK4I=Z(K,4,I)                                                         HCPS0560
      ZK3I=Z(K,3,I)                                                         HCPS0570
      ZK2I=Z(K,2,I)                                                         HCPS0580
      ZK1I=Z(K,1,I)                                                         HCPS0590
      S0(IS)=TK5*ZK5I+TK4*ZK4I+TK3*ZK3I+TK*ZK2I+TLN*ZK1I+Z(K,7,IS)          HCPS0600
30    B0(IS)=TK5*ZK5I+TK4*ZK4I+TK3*ZK3I+TK2*ZK2I+ZK1I+Z(K,6,IS)*TKINV      HCPS0610
      RETURN                                                                HCPS0620
      END                                                                   HCPS0630
```

LISTING OF DATA CARDS

```
ELEMENTS                                                                    0001
C         12.01115   4.0                                                    0002
H         1.00797    1.0                                                    0003
O         15.9994    -2.0                                                   0004
N         14.0067    0.0                                                    0005
                                                                            0006
THERMO  FOR CH4/AIR COMBUSTION WITH NOX                                     0007
N                    J 3/61N  1.00 0.00 0.00 0.G   300.000  5000.000        0008
 0.24502678F 01 0.10661458E-03-0.74653315E-07 0.18796520E-10-0.10259837F-14 0009
 0.56116035F 05 0.44487572E 01 0.25030699E 01-0.21800181F-04 0.54205284E-07 0010
-0.56475602F-10 0.20999038E-13 0.56098898E 05 0.41675749E 01                0011
NO                   J 6/63N  1.0  1.00 0.00 0.G   300.000  5000.000        0012
 0.31889992F 01 0.13382279E-02-0.52899316E-06 0.95919314E-10-0.64847928F-14 0013
 0.98283242F 04 0.67458115E 01 0.40459509E 01-0.34181783E-02 0.79819174F-05 0014
-0.61139254F-08 0.15919072E-11 0.97453867E 04 0.29974976E 01                0015
NO2                  J 9/64N  1.0  2.00 0.00 0.G   300.000  5000.000        0016
 0.46240759F 01 0.25260330E-02-0.10609483F-05 0.19879239F-09-0.13799300F-13 0017
 0.22899900F 04 0.13324137E 01 0.34589224E 01 0.20647063E-02 0.66866060F-05 0018
-0.95556665F-08 0.36195873E-11 0.28152261E 04 0.83116980E 01                0019
N2O                  J12/64N  2.0  1.00 0.00 0.G   300.000  5000.000        0020
 0.47306662F 01 0.28258264E-02-0.11558104E-05 0.21263681E-09-0.14564061F-13 0021
 0.81617617F 04-0.17151070E 01 0.26189194E 01 0.86439550E-02-0.68110612F-05 0022
 0.22275877F-08-0.80650276E-13 0.87590078E 04 0.92266951E 01                0023
N2                   J 9/65N  2.0  0.0  0.0  0.G   300.000  5000.000        0024
 0.28963194F 01 0.15154863E-02-0.57235275F-06 0.99807385E-10-0.65223536F-14 0025
-0.90586182F 03 0.61615143E 01 0.36748257F 01-0.12081496F-02 0.23240100F-05 0026
-0.63217520F-09-0.22577253E-12-0.10611587F 04 0.23580418E 01                0027
CH4                  J 3/61C   1H   400  000  0G   300.000  5000.000       1 0028
 0.15027072F 01 0.10416798E-01-0.39181522E-05 0.67777899F-09-0.44283706E-13 2 0029
-0.99787078F 04 0.10707143E 02 0.38261932E 01-0.39794581E-02 0.24558340E-04 3 0030
-0.2273292GF-07 0.69626957E-11-0.10144950E 05 0.86690073E 00                4 0031
O2                   J 9/650  2.0  0.0  0.0  0.G   300.000  5000.000        0032
 0.36219521F 01 0.73618256E-03-0.1965223 9F-06 0.36201556E-10-0.28945623F-14 0033
-0.12019822F 04 0.36150942E 01 0.3625599 0E 01-0.18782183E-02 0.70554543E-05 0034
-0.67635071F-08 0.21555977E-11-0.1047522 5E 04 0.43052769E 01                0035
CO                   J 9/65C  1.0  1.00 0.00 0.G   300.000  5000.000        0036
```

```
 0.29840689E 01 0.14891387E-02-0.5789567BE-06 0.10364376E-09-0.69353499E-14      _0037
-0.14245227E 05 0.63479147E 01 0.37100916E 01-0.16190964E-02 0.36923584E-05      _0038
-0.20319673E-08 0.23953344E-12-0.14356309E 05 0.29555340E 01                     _0039
CO2                 J 9/65C  1.0  2.00 0.00 0.G    300.000  5000.000            _0040
 0.44608040E 01 0.30981717E-02-0.12392566E-05 0.22741323E-09-0.15525948E-13      _0041
-0.48961438E 05-0.98635978E 00 0.24007788E 01 0.87350905E-02-0.66070861E-05      _0042
 0.20021860E-08 0.63274039E-15-0.48377520E 05 0.96951447E 01                     _0043
H                   J 9/65H  1.00 0.00 0.00 0.G    300.000  5000.000            _0044
 0.25000000E 01 0.0             0.0             0.0             0.0             _0045
 0.25471625E 05-0.46011758E 00 0.25000000E 01 0.0             0.0             _0046
 0.0            0.0             0.25471625E 05-0.46011758E 00                   _0047
H2                  J 3/61H  2.0   0.0  0.0  0.G    300.000  5000.000            _0048
 0.31001883E 01 0.51119458E-03 0.52644204E-07-0.34909964E-10 0.36945341E-14      _0049
-0.87738013E 03-0.19629412E 01 0.30574446E 01 0.26765198E-02-0.58099149E-05      _0050
 0.55210343E-08-0.18122726E-11-0.98890430E 03-0.22997046E 01                     _0051
H2O                 J 3/61H  2.0  1.00 0.00 0.G    300.000  5000.000            _0052
 0.27167616E 01 0.29451370E-02-0.80224368E-06 0.10226681E-09-0.48472104E-14      _0053
-0.29905820E 05 0.66305666E 01 0.40701275E 01-0.11084499E-02 0.41521180E-05      _0054
-0.29637404E-08 0.80702101E-12-0.30279719E 05-0.32270038E 00                     _0055
O                   J 6/62O  1.00 0.00 0.00 0.G    300.000  5000.000            _0056
 0.25420580E 01-0.27550603E-04-0.31028029E-08 0.45510670E-11-0.43680494E-15      _0057
 0.29230801E 05 0.49203072E 01 0.29464263E 01-0.16381664E-02 0.24210303E-05      _0058
-0.16028432E-08 0.38906964E-12 0.29147641E 05 0.29639931E 01                     _0059
OH                  J 3/66O  1.n  1.00 0.00 0.G    300.000  5000.000            _0060
 0.29106417E 01 0.95931627E-03-0.19441700E-06 0.13756646E-10 0.14224542E-15      _0061
 0.39353811E 04 0.54423428E 01 0.38375931E 01-0.10778855E-02 0.96830354E-06      _0062
 0.18713971E-09-0.22571089E-12 0.36412820E 04 0.49370009E 00                      0063
                                                                                 _0064
MECHANISM                                                                        _0065
N       NO              N2      O               10.1760  0.0     0.0     WALD7/74_0066
N       O2              NO      O               6.778    1.0     3172.   WALD7/74_0067
OH      N               H       NO              8.778    0.5     4028.   WALD7/74_0068
H       H2O             OH      N2              10.903   0.0     7553.   WALD7/74_0069
N2O     O               NO      NO              11.000   0.0     15000.  WALD7/74_0070
N2O             M       N2      O       M       11.000   0.0     25176.  WALD7/74_0071
N       O       M       NO      M               10.806   -0.5                    _0072
NO2     O               NO      O2              10.000   0.0       300.          _0073
NO2     M               O       NO      M       13.041   0.0     33000.        _0074
                                                                                 _0075
```

APPENDIX C - GLOSSARY OF FORTRAN VARIABLES

Note: A number of Fortran variables, which are used locally in NASCO II, are not listed below. However, the user should be able to derive their meaning from the context in which they are used.

NAME	LOCATION	TYPE	MEANING
A	COEFF	Array	Finite-difference coefficient.
A	CALC	Array	Elements of the correction matrix.
AC1-AC4	BLOCK DATA		Polynomial coefficients for specific heat of equilibrium-product-species.
AE	COEFF	Array	Finite-difference coefficient.
AEDDX	GEOM	Array	Ratio of area to the internodal distance for east face of the cell.
AH1-AH4	BLOCK DATA		Polynomial coefficients for enthalpy of equilibrium-product-species.
AK	BLOCK DATA		Von Karman constant.
AK	REACT		Temporarily stored quantity.
AL	REACT	Array	Atomic stoichiometric coefficients; AL (I,J) is the kg-atoms of element I per kg-mole of species J.
ALNR1I	MAIN		$\ell n\ (r_{1,m}/r_{1,i})$.
ALNR10	MAIN		$\ell n\ (r_{1,0}/r_{1,m})$.
ALNR2I	MAIN		$\ell n\ (r_{2,m}/r_{2,i})$.
ALNR20	MAIN		$\ell n\ (r_{2,0}/r_{2,m})$.
AMCH	REACT		Alphanumeric storage for "MECH".
AN	COEFF	Array	Finite-difference coefficient.
ANDDY	GEOM	Array	Ratio of area to the internodal distance for north face of the cell.

NAME	LOCATION	TYPE	MEANING
AREA	ADJUST		Total flow area normal to the x-direction.
AREAE	GEOM	Array	Area of east face of a continuity cell.
AREAN	GEOM	Array	Area of north face of a continuity cell.
ARG	WALL		Logarithm of argument.
ARGMIN	WALL		Smallest value of ARG.
ARRCON	BLOCK DATA		Arrhenius constant, E/R.
ARSL	COEFF	Array	Sum of absolute values of RSLINE.
AS	COEFF	Array	Finite-difference coefficient.
ASM1-ASM4	BLOCK DATA	Array	Polynomial coefficients for reciprocal mean molecular weight of equilibrium-product-species.
ASNIP	COEFF	Array	Finite-difference coefficient used in performing SNIP. (see Section 3.3.5).
ASUB	REACT	Array	Molecular symbol for species.
AS1	BLOCK DATA	Array	Polynomial coefficients for concentration of equilibrium-product-species.
AT	REACT	Array	Atomic symbol for species.
ATOM	REACT	Array	For element K, ATOM (1,K) = Atomic symbol; ATOM (2,K) = Atomic weight; ATOM (3,K) = Valence or oxidation state.
AW	COEFF	Array	Finite-difference coefficient.
B	COEFF	Array	Finite-difference coefficient.
BIG	BLOCK DATA		A large number.

NAME	LOCATION	TYPE	MEANING
BLANK	OUTPUT, REACT		Alphanumeric storage for 4 blank spaces.
BSNIP	COEFF	Array	Finite-difference coefficient used in performing SNIP. (see Section 3.3.5).
BX	REACT	Array	Arrhenius pre-exponential factor for forward reaction.
BX2	REACT	Array	Arrhenius pre-exponential factor for backward reaction.
C	COEFF	Array	Finite-difference coefficient.
CCHECK	BLOCK DATA		Convergence criterion for sum of residual errors.
CE, CN, CS, CW	COEFF		Convective fluxes (E=east face, N=North face, etc.).
CMIX	BLOCK DATA		Specific heat of mixture.
COND	BLOCK DATA		Thermal conductivity.
CONVG	SPECE		Parameter to indicate convergence of chemical-kinetics solution.
CPR	CHEM		Specific heat of equilibrium-product-species.
CPSUM	HCPS		Specific heat of mixture.
CSNIP	COEFF	Array	Finite-difference coefficient used in performing SNIP. (see Section 3.3.5).
D	COEFF	Array	Finite-difference coefficient.
DATA	OUTPUT	Array	Temporary storage before printout.
DATA	REACT	Array	Temporary storage for reading in data.
DE,DN, DW	COEFF		Diffusion fluxes (E=East face, N=North face, etc.).

NAME	LOCATION	TYPE	MEANING
DELU	ADJUST		Increment in values of U along a line resulting from an overall continuity correction.
DIFE	COEFF	Array	Arrays used to store the diffusion fluxes through the faces of a continuity cell. (E=East, EE=East-east; N=North; NE=North-east; NW=North-west; W=West; WW=West-west face.)
DIFEE	COEFF	Array	
DIFN	COEFF	Array	
DIFNE	COEFF	Array	
DIFNW	COEFF	Array	
DIFW	COEFF	Array	
DIFWW	COEFF	Array	
DP	ADJUST		Pressure increment.
DSNIP	COEFF	Array	Finite-difference coefficient used in performing SNIP. (see Section 3.3.5).
DTEMP	MAIN,CHEM		Fractional temperature increment.
DT1	REACT		Quantities used during input of thermochemical data.
DT2	REACT		
DU	COEFF	Array	Influence coefficient used in the correction of u-velocity.
DV	COEFF	Array	Influence coefficient used in the correction of v-velocity.
DXG	GEOM	Array	Difference in the x-coordinate values between two adjacent grid nodes.
DXU	GEOM	Array	Difference in the x-coordinate values between two adjacent u-locations.
DYG	GEOM	Array	Difference in the y-coordinate values between two adjacent grid nodes.
DYV	GEOM	Array	Difference in the y-coordinate values between two adjacent v-locations.
ELEM	REACT		Alphanumeric storage for 'ELEM'.
EL1-EL3	BLOCK DATA		Dimensions of combustor L_1, L_2, L_3 (Fig.1).

NAME	LOCATION	TYPE	MEANING
EMA,EMF	BLOCK DATA		Mass flow rates of air and fuel at inlet.
EMIS10 EMIS2I EMIS20 EMISXI EMISXO	BLOCK DATA		Emissivities: 10=Outer surface of inner wall; 2I=inner surface of outer wall; 20=Outer surface of outer wall; XI=inner surface of end wall; X0=outer surface of end wall.
EMU	MAIN	Array	Effective viscosity.
EMUREF	BLOCK DATA		Reference viscosity (=laminar viscosity).
EMUT	MAIN		Turbulent viscosity.
EMV	CHEM		Total convective and diffusive mass inflow to a cell.
ENTH	MAIN, CHEM		Enthalpy.
ENTHB	MAIN		Enthalpy of B-stream.
ENTHC	MAIN		Enthalpy of C-stream.
EPSS	BLOCK DATA		Convergence criterion for species concentrations.
EPST	BLOCK DATA		Convergence criterion for temperature.
EQRAT	OUTPUT		Equivalence ratio.
ER	WALL		EWALL* Reynolds number.
ESMASS	SOURCE		Source term for continuity equation.
ETA	SPECE		Under-relaxation parameter.
ETA1	SPECE		Under-relaxation parameter.
EWALL	BLOCK DATA		Constant in wall function.
F	MAIN	Array	An array used to store all the dependent and auxiliary variables.
FACTOR	MAIN		Temporarily stored quantity.

NAME	LOCATION	TYPE	MEANING
FFU	MAIN, CHEM		Mass fraction of fuel.
FJF	SOURCE		Mass fraction of fuel.
FJP	CHEM		Mixture fraction.
FLOB	MAIN		Flow rate in B-stream.
FLOC	MAIN		Flow rate in C-stream.
FLOWE FLOWEE	FLOWM FLOWM	Array Array	Convective fluxes through the east and east-east faces of a finite-difference cell.
FLOWIN	MAIN		Total inlet mass flow rate (air+fuel).
FLOWN FLOWNE FLOWNW	FLOWM FLOWM FLOWM	Array Array Array	Convective fluxes through the north, north-east and north-west faces.
FLOWST	ADJUST		Mass flow rate based on the starred velocities.
FLOWUP	ADJUST		Mass flow rate through the plane upstream (in the sweep direction) of the one being considered.
FLOWW FLOWWW	FLOWM FLOWM	Array Array	Convective fluxes through the west and west-west faces.
FM	MAIN	Array	Mixture fraction.
FN2	CHEM		Nitrogen mass fraction.
FO2	CHEM		Mass fraction of oxygen.
FPR	CHEM		Mass fraction of equilibrium-product-species.
FS	MAIN	Array	Mass fractions of species.
FSII	CHEM		Temporary storage for FS.

NAME	LOCATION	TYPE	MEANING
FSTOIC	MAIN		Stoichiometric mixture fraction.
FSTOIM	MAIN		1.0 - FSTOIC.
FUB	BLOCK DATA		Fuel mass-fraction in B-stream.
FUBRNT	SOURCE		Fuel mass-fraction in fully-burnt gas.
FUC	BLOCK DATA		Fuel mass-fraction in C-stream.
FUE	MAIN	Array	Unburnt fuel mass fraction.
FUEX	SOURCE		Excess fuel.
GASCON	BLOCK DATA		Universal gas constant.
GAZ	REACT		Alphanumeric storage for 'G' (for gas).
GF	REACT		Temporarily stored quantity.
H	MAIN	Array	Stagnation enthalpy.
HDIV	BLOCK DATA		Intermediate enthalpy value for the coefficients AS1.
HFU	BLOCK DATA		Heat of combustion of fuel.
HMAX	BLOCK DATA		Maximum enthalpy value for the coefficients AS1.
HMIN	BLOCK DATA		Minimum enthalpy value for the coefficients AS1.
HMIX	CHEM		Mixture enthalpy.
HPR	CHEM		Enthalpy of equilibrium-product-species.
HSUM	MAIN		Enthalpy of mixture.
HO	MAIN	Array	Enthalpy of species.
HW	BLOCK DATA		Recovery factor.

NAME	LOCATION	TYPE	MEANING
I			Index, generally used to define the storage location of a variable (other than v or p) at a given grid node.
ICONST			=IX2NY2-1.
ID	REACT		ID (K,J) is the species index number of species K in reaction J.
IDASH	COEFF		Index in back-substitution for TDMA.
IDCO	BLOCK DATA		Index for CO.
IDCO2	BLOCK DATA		Index for CO2.
IDEBUG	BLOCK DATA		Index for chemical-kinetics diagnostic output; =0, no output; =1, output obtained.
IDF	BLOCK DATA		Index for fuel.
IDH	BLOCK DATA		Index for H.
IDH2	BLOCK DATA		Index for H2.
IDH20	BLOCK DATA		Index for H20.
IDN	BLOCK DATA		Index for N.
IDNO	BLOCK DATA		Index for NO.
IDNO2	BLOCK DATA		Index for NO2.
IDN2	BLOCK DATA		Index for N2.
IDN20	BLOCK DATA		Index for N20.
IDO	BLOCK DATA		Index for 0.
IDOH	BLOCK DATA		Index for OH.
IDO2	BLOCK DATA		Index for 02.

NAME	LOCATION	TYPE	MEANING
IE, IN INE, INW, etc.,			Storage locations for neighbouring nodes around the one corresponding to the storage location I or IV; IE for the eastern one, INW for the north-western one, and so on.
IEP			Storage location for p-node at the east of the one corresponding to IP.
IEQUIL	BLOCK DATA		=0, equilibrium concentrations not obtained. =1, equilibrium concentrations obtained.
IEW	CONST	Array	The number of nodes in the r-direction at which values of a dependent variable are stored.
IHCPS	MAIN		Index to control calculation of thermodynamic properties.
ILAST	CONST	Array	The last location in the F-array for a given variable.
IMAT	SPECE		Number of rows in Newton -Raphson correction matrix.
IMON	CONST	Array	Index to denote the grid node (IXMON, IYMON) for use in monitoring the progress of the iterative solution.
INC	MAIN		=1, sweep in positive x-direction; =-1, sweep in negative x-direction.
INERT	BLOCK DATA		Indicator of chemically-inert/reacting flow: =1, Chemically inert; =2, Chemically reacting.
IP			Index used to define the storage location of a p-node.
IPLRS	BLOCK DATA		Number of sweeps after which residual errors are printed out.
IPR	BLOCK DATA		Index number for products.

NAME	LOCATION	TYPE	MEANING
IPREF	CONST		Index used to define the storage location of the reference-pressure node.
IPRINT	BLOCK DATA		Index to control type of printout required, i.e. field values of dependent variables are printed after every IPRINT iterative sweeps.
ISNIP	MAIN		=0, SNIP is performed; =1, SNIP is not performed (See Section 3.3.5)
ISWEEP	MAIN		Variable counter for the iteration sweep number.
IT	MAIN, CHEM		Number of iterations on temperature.
ITER	SPECE		Number of iterations during chemical-kinetics computations.
ITMAX	BLOCK DATA		Maximum number of iterations of chemical-kinetics computations.
IV			Index used to define the storage location of a v-velocity node.
IVE, IVN IVS, etc			Storage locations for neighbouring v-nodes around the one corresponding to IV - IVE for eastern one; IVN for northern one; and so on.
IX			The grid-line number for an X-constant line on which variables are being updated.
IX1NY	MAIN		=(IX-1)*NY.
IX1NY1	MAIN		=(IX-1)*NYM1.
IX2NY2	MAIN		=(IX-2)*NYM2.
IX1NYU	MAIN		=(IXU-1)*NY.
IX2NYU	MAIN		=(IXU-2)*NYM2.

NAME	LOCATION	TYPE	MEANING
IXMON, IYMON	BLOCK DATA		(IXMON, IYMON) is the location of the grid node at which values of the variables are printed out at each iteration for monitoring the numerical process.
IXNY	CONST	Array	Variable to facilitate computing the location in the storages for the variable denoted by J at a grid node on the line where variables are being updated. For example, I=IY+IXNY(JV) gives the storage location, I, in the V-array at the grid node (IX,IY), IX having been included into IXNY (JV).
IXP1	MAIN		=IX+1.
IXPREF IYPREF	BLOCK DATA		(IXPREF, IYPREF) is the location of the grid node where the pressure is taken as the reference value.
IXU	MAIN		IX-location of u-velocity currently being solved for.
IXUP1	MAIN		IXU+1.
IXW	BLOCK DATA		Index denoting end of inner tube in x-direction.
IY			An index used to denote the (IY)th grid node on the line where variables are being updated.
IYF, IYL	MAIN		The first and last IY-locations in the domain of integration.
IYFM1	MAIN		=IYF-1.
IYFP1	MAIN		=IYF+1.
IYFUEL	BLOCK DATA		IY location of incoming fuel stream.
IYLM1	MAIN		=IYL-1.
IYLP1	MAIN		=IYL+1.
IYM1			=IY-1.

NAME	LOCATION	TYPE	MEANING
IYW	BLOCK DATA		Index denoting location of inner tube in y-direction.
IYWM1	MAIN		=IYW-1.
IYWP1	MAIN		=IYW+1.
IZERO	CONST	Array	The location in the F-array that is immediately in front of the first of the storages for the variable denoted by J.
JEMU	BLOCK DATA		Index for effective viscosity.
JFM	BLOCK DATA		Index for mixture fraction.
JFUE	BLOCK DATA		Index for unburnt fuel mass fraction.
JH	BLOCK DATA		Index for stagnation enthalpy.
JJ	REACT		Number of chemical reactions.
JLAST	BLOCK DATA		Maximum index number for variables stored in F-array.
JP	BLOCK DATA		Index for pressure.
JPHI			Index for general variable ϕ.
JPP	BLOCK DATA		Index for pressure-correction.
JRHO	BLOCK DATA		Index for density.
JS1, JS2	BLOCK DATA		Indices for first and last chemical species in F-array.
JTEM	BLOCK DATA		Index for temperature.
JU, JV	BLOCK DATA		Indices for u and v velocities.
KASE			Index denoting problem.
KGOTO			Index used in a subroutine argument list to access the appropriate part of the subroutine on any call.

NAME	LOCATION	TYPE	MEANING
KINPRI	BLOCK DATA		Control index for print-out of initially assigned values of variables in field, =0, of no print-out of these needed; =1, if print-out wanted.
KLT	BLOCK DATA		Index to denote type of flow; i.e. laminar (1) or turbulent (2).
KMAT	SPECE		IMAT + 1.
KNTCS	BLOCK DATA		=0, chemical-kinetics computations suppressed; =1, chemical-kinetics computations performed.
KOUNT	MAIN	Array	An array used to store for each TDMA line the maximum number of TDMA traverses made, this number being. LE. NTDMA.
KRAD	BLOCK DATA		Control index for cartesian or cylindrical polar (axisymmetrical) coordinates, =1 for cartesian; =2 for cylindrical polar.
KRHOMU	CONST		=KSOLVE (JRHO) + KSOLVE (JEMU).
KSOLVE	BLOCK DATA	Array	Control index to govern whether the variable denoted by J requires updating in the numerical process, J covering the whole range of variables under the F-array; =0, if not to be updated; =1, if updating required.
KSWEEP	BLOCK DATA		Number of sweeps after which chemical-kinetics computations are started.
KTEST	BLOCK DATA		Control index for diagnosing print out levels; =0, if no such print-out is required; =1, prints out the following geometrical quantities related to the grid, variable information initial values assigned in the field;

NAME	LOCATION	TYPE	MEANING
			=2 prints out those for 1 and the following - starred velocities and velocity residual-sources on the TDMA line, also quantities related to the overall mass-continuity adjustment and the cell-wise-continuity correction; =3 prints out those for 2 and the coefficients in the general form of the finite-difference equation for all the dependent variables.
LABPHI			A variable for transferring the value of JPHI from one subroutine to another one that does not have JPHI as an argument.
LPHI			Index for general variable ϕ.
LSWEEP	BLOCK DATA		Maximum number of iterative sweeps to be performed.
MODE	CALC		Type of reaction.
NA	SPECE		NS + 1.
NCD	REACT		Index used during input of thermo-chemical data.
ND	REACT		Index during computation of ID.
NLM	REACT		Number of elements.
NS	BLOCK DATA		Number of chemical species.
NSE1	BLOCK DATA		Index for first equilibrium-product-species.
NSE2	BLOCK DATA		Index for the last equilibrium-product-species.
NSK	BLOCK DATA		Number of species whose concentrations are kinetically determined.
NSK1	CALC		NSK + 1.
NSM	REACT		NS + 1.
NSOLVE	BLOCK DATA		Number of variable equations to be solved.

NAME	LOCATION	TYPE	MEANING
NS1 NS2	MAIN MAIN	}	First and last species numbers for computation of thermodynamic properties.
NTDMA	BLOCK DATA		Maximum number of TDMA traverses along any one grid line.
NTMAX	BLOCK DATA		Maximum number of iterations on temperature.
NTRAV	MAIN		The number of traverses being performed on a line at any sweep.
NUMCOL	BLOCK DATA		Number of columns to be printed out.
NX	BLOCK DATA		Number of X-constant grid lines in the flow domain.
NXMAX	BLOCK DATA		Maximum number of X-constant grid lines that can be used to cover the flow domain without changing the dimensions of the variable arrays.
NXM1 NXM2	CONST CONST		=NX-1. =NX-2.
NXYG	CONST		=NX * NY, is the total number of locations where scalar quantities other than pressures are stored.
NXYP	CONST		=(NX-2)*(NY-2), is the total number of locations where pressure values are stored. (Pressure values at flow boundaries are not stored).
NXYU	CONST		=(NX-1)*NY, is the total number of locations where the X- component velocity values, U, are stored.
NY	BLOCK DATA		Number of Y-constant grid lines in the flow domain.

NAME	LOCATION	TYPE	MEANING
NYMAX	BLOCK DATA		Maximum number of Y-constant grid lines that can be used to cover the flow domain without changing the dimensions of the variable arrays.
NYM1	CONST		=NY-1.
NYM2	CONST		=NY-2.
OXB	BLOCK DATA		Oxygen mass-fraction in B-stream.
OXBRNT	MAIN		Oxygen mass-fraction in fully-burnt gas.
OXC	BLOCK DATA		Oxygen mass-fraction in C-stream.
P	MAIN	Array	Pressure.
PA	CHEM		Pressure.
PDGSCN	MAIN, CHEM		Pressure ÷ Gas constant.
PEXP	BLOCK DATA	Array	Exponent on pressure in chemical-equilibrium calculations.
PHAZ	REACT		Phase of species for which thermochemical data is read.
PHI	CHEM		Temporary storage for $(f-f_{st})/(1-f_{st})$.
PP	COEFF	Array	Pressure-correction.
PRB	MAIN		Mass fractions of (products +N2) in B-stream.
PRC	MAIN		Mass fractions of (products +N2) in C-stream.
PREEXP	BLOCK DATA		Arrhenius pre-exponential factor.
PREFF	MAIN	Array	Effective Prandtl/Schmidt number.
PRESS	BLOCK DATA		Pressure.

NAME	LOCATION	TYPE	MEANING
PRL	BLOCK DATA	Array	Laminar Prandtl/Schmidt number.
PRT	BLOCK DATA	Array	Turbulent Prandtl/Schmidt number.
R	GEOM	Array	Radius.
RDXG	GEOM	Array	Reciprocal of DXG.
RDXU	GEOM	Array	Reciprocal of DXU.
RDYG	GEOM	Array	Reciprocal of DYG.
RDYV	GEOM	Array	Reciprocal of DYV.
RECTK	CALC		Reciprocal of TK.
RELAXP	BLOCK DATA		Under-relaxation factor for pressure.
REMI			=1.0/EMIS2I-1.0.
REY	WALL		Reynolds number.
RF	BLOCK DATA		Radius of incoming fuel jet.
RFSTM	MAIN		1.0/FSTOIM.
RHDIFF	CHEM		Reciprocal of (HMAX-HMIN).
RHO	MAIN	Array	Density.
RHOB	MAIN		Density of B-stream.
RHOC	MAIN		Density of C-stream.
RHOINF	BLOCK DATA		Density of surroundings.
RHOP	CALC		Density.
RHOREF	MAIN		Reference density.
RHSM	CALC		Density ÷ Molecular weight.
RHSMP	CALC		RHSM* Density.

NAME	LOCATION	TYPE	MEANING
RHSMSQ	CALC		RHSM* square of density.
RHSQ	CALC		Square of density.
RPREFF	COEFF		Reciprocal of Prandtl/Schmidt number.
RSLINE	COEFF	Array	Algebraic sum of residual-sources at a given line for a given variable.
RSCHEK	BLOCK DATA		Convergence criterion for residuals at a line.
RSMAX	COEFF		Largest of the magnitudes of residual-source sums of all the variables.
RSMW	REACT		Reciprocal of SMW.
RSREF	MAIN	Array	Normalising factors for residual-errors.
RSSUM	COEFF	Array	Sum of residual sources for a given variable.
RSXG	GEOM	Array	Reciprocal of SXG.
RSXU	GEOM	Array	Reciprocal of SXU.
RSYG	GEOM	Array	Reciprocal of SYG.
RSYV	GEOM	Array	Reciprocal of SYV.
RV	GEOM	Array	r-coordinates of the v-nodes.
RVCB	GEOM	Array	r-coordinates of the v-cell.
RVSQ	GEOM	Array	Square of RV.
RVRS	REACT		Alphanumeric storage for 'REVE'.
R1	CALC		Forward reaction rate.
R1I	BLOCK DATA		Inner radius of inner tube.
R10	BLOCK DATA		Outer radius of inner tube.

NAME	LOCATION	TYPE	MEANING
R2	CALC		Backward reaction rate.
R2I	BLOCK DATA		Inner radius of outer tube.
R2M	MAIN		=0.5*(R2I+R20).
R20	BLOCK DATA		Outer radius of outer tube.
S	WALL, SOURCE		Shear stress coefficient.
SHALF	WALL, SOURCE		Square root of S.
SHALF1	WALL, SOURCE		Square root of S.
SIGMA	BLOCK DATA		Stefan-Boltzmann constant.
SM	REACT		Reciprocal of mean molecular weight of mixture.
SMW	REACT	Array	Molecular weight of species.
SP	SOURCE	Array	Part of linearised source term.
SP1	CHEM		STOICH + 1.0.
STOICH	BLOCK DATA		Stoichiometric ratio.
STORE		Array	Used for temporarily stored quantities.
STXI	BLOCK DATA		Stanton number at inner surface of end wall.
STX 0	BLOCK DATA		Stanton number at outer surface of end wall.
ST1I	BLOCK DATA		Stanton number at inner surface of inner tube.
ST10	BLOCK DATA		Stanton number at outer surface of inner tube.
ST2I	BLOCK DATA		Stanton number at inner surface of outer tube.

NAME	LOCATION	TYPE	MEANING
ST20	BLOCK DATA		Stanton number at outer surface of outer tube.
SU	SOURCE	Array	Part of linearised source term.
SUMX	REACT		Sum of x's*.
SUMY	REACT		Sum of y's*.
SUM1	REACT		Temporarily stored quantity.
SXG	GEOM	Array	The x-direction length of a ϕ-cell.
SXU	GEOM	Array	The x-direction length of a u-cell.
SYG	GEOM	Array	The r-direction length of a ϕ-cell.
SYV	GEOM	Array	The r-direction length of a v-cell.
S0	HCPS	Array	One-atmosphere, ideal gas entropy of species.
S1	CHEM	Array	Species mole-numbers averaged over four neighbouring nodes.
S2	CHEM	Array	Species mole-number.
TACT	REACT	Array	Activation temperature (E/R) for forward reaction.
TACT2	REACT	Array	Activation temperature (E/R) for backward reaction.
TB	BLOCK DATA		Temperature of B-stream.
TC	BLOCK DATA		Temperature of C-stream.
TEM	MAIN	Array	Absolute temperature.
TEN	REACT	Array	Exponent on temperature in forward reaction rate expression.
TENLN	REACT		&n (10).

*x and y are used for temporary storage of some quantities in subroutine REACT.

NAME	LOCATION	TYPE	MEANING
TEN2	REACT	Array	Exponent on temperature in backward reaction rate expression.
THIRD	REACT, OUTPUT		Alphanumeric storage for 'M' (third body in chemical reaction).
THRM	REACT		Alphanumeric storage for 'THER'.
TINY	BLOCK DATA		A small number.
TINYK	BLOCK DATA		A small number for chemical-kinetics calculations.
TITLE	BLOCK DATA	Array	Alphanumeric storage to identify a dependent variable.
TK	CHEM		Temperature.
TK1.. TK5	HCPS		Temporarily stored quantities.
TLN	REACT		ℓn (temperature).
TMAX	BLOCK DATA		Maximum temperature in the calculations.
TMIN	BLOCK DATA		Minimum temperature in the calculations.
TM1	REACT		Temporarily stored quantity.
TM1	CALC		R1 - R2.
TM2.. TM5	HCPS		Temporarily stored quantities.
TNY	BLOCK DATA		ℓn (TINYK).
TST1	SPECE		Temporarily stored quantity.
T1	SOURCE		Temporarily stored quantity (=PREEXP* PRESS**2).
T1	REACT		Quantities used during input of thermochemical data.
T2	REACT		

NAME	LOCATION	TYPE	MEANING
U	MAIN	Array	Longitudinal velocity component.
UB	BLOCK DATA		Velocity of B-stream.
UC	BLOCK DATA		Velocity of C-stream.
UINF	BLOCK DATA		Free stream u-velocity.
V	MAIN	Array	Radial velocity component.
VINF	BLOCK DATA		Free stream v-velocity.
VMIX	MAIN		Specific volume of mixture.
VOL	GEOM	Array	Volume of a finite-difference cell.
WAREA	MAIN		=0.5(R20**2 - R2I**2).
WB	MAIN		Reciprocal molecular weight of B-stream.
WC	MAIN		Reciprocal molecular weight of C-stream.
WMIX	BLOCK DATA		Molecular weight of mixture.
X	BLOCK DATA	Array	x-coordinates of the ϕ-nodes.
X	CALC	Array	Corrections in chemical-kinetics calculations.
XBAR	REACT		Average value of X.
XMAX	REACT		Maximum x-value.
XMIN	REACT		Minimum x value.
XU	GEOM	Array	x-coordinates of the u-nodes.
Y	BLOCK DATA	Array	r-coordinates of the ϕ-nodes.
Y	SPECE	Array	Logarithms of species mole-numbers.
YBAR	REACT		Average value of Y.

NAME	LOCATION	TYPE	MEANING
YV	GEOM	Array	r-coordinates of the v-nodes.
Z	REACT	Array	Coefficients for calculation of thermochemical data.
ZK1I.. ŻK5I	HCPS		Temporarily stored quantities.

APPENDIX D

LISTING OF THE OUTPUT FROM THE NASCO II PROGRAM

Interpretation of the Output from NASCO II

In this section the details of the output supplied with this report are provided to enable the reader to understand the output.

The first item of print-out gives details of the problem specifying parameters, and is self-explanatory.

The second item of print-out specifies the initial guessed fields of the dependent variables. Each field variable ϕ is given in a table of the following form:

----------FIELD VARIABLE (ϕ) ----------

y locations of
grid for which
value is printed

x locations of
grid for which
value is printed

This item of printout is repeated at every IPRINT iterative sweeps; odd-numbered sweeps refer to sweeps in the positive-x direction and even numbered sweeps to sweeps in the negative-x direction.

The third item of print-out gives details of the residuals along lines for the dependent variables, and also the sums of the absolute values of these residuals for the whole field.

The residuals are normalised over-all balance quantities, departures of which from zero give information about the extent to which errors in the finite-difference equations remain to be eliminated. For details the reader is advised to refer to Appendix D of Reference 1.

The fourth item of printout gives the values of the dependent variables at a particular monitoring location; in the present output at the node (3,3).

PREDICTION OF HYDRODYNAMICS AND
CHEMISTRY OF A TWO-CONCENTRIC-TUBE
COMBUSTOR WITH ATTENTION
TO POLLUTANT FORMATION

THE NASCO II COMPUTER PROGRAM

PREPARED BY

CONCENTRATION, HEAT AND MOMENTUM LTD.

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA LEWIS RESEARCH CENTER

CONTRACT NASW-3077

APRIL 1978

RESULTS FOR TEST CASE 2

S.I. UNITS ARE USED THROUGHOUT

FLOW CONDITIONS
==========

TURBULENT, KLT=2

CHEMICALLY REACTING, INERT=2

GEOMETRY
========

RF	R1I	R1O	R2I	R2O
1.00E-03	3.00E-03	3.50E-03	9.00E-03	1.05E-02

EL1	EL2
2.00E-01	1.00E-02

INLET CONDITIONS
==========

FLOW RATE OF FUEL, EMF	1.400E-05
FLOW RATE OF AIR, EMA	3.600E-04
VELOCITY OF FUEL STREAM, UB	3.176E+00
VELOCITY OF AIR STREAM, UC	5.677E+00
TEMPERATURE OF FUEL STREAM, TB	2.750E+02
TEMPERATURE OF AIR STREAM, TC	2.750E+02
INLET PRESSURE, PRESS	2.000E+05
REYNOLDS NUMBER	4.409E+03
OVERALL EQUIVALENCE RATIO, EQRAT	6.705E-01
TOTAL MASS FLOW RATE, FLOWIN	5.952E-05

POLYNOMIAL COEFFICIENTS FOR THERMODYNAMIC PROPERTIES.
14 COEFFICIENTS ((Z(K,J,I),J=1,7),K=1,2) FOR EACH SPECIES I.

```
N
    1.749E-01  7.612E-06 -5.330E-09  1.342E-12 -7.325E-17  4.006E+03
    3.176E-01  1.787E-01 -1.556E-06  3.870E-09 -4.032E-12  1.499E-15
    4.005E+03  2.975E-01

NO
    1.063E-01  4.460E-05 -1.763E-08  3.197E-12 -2.161E-16  3.275E+02
    2.248E-01  1.348E-01 -1.139E-04  2.660E-07 -2.030E-10  5.305E-14
    3.248E+02  9.990E-02

NO2
    1.005E-01  5.491E-05 -2.306E-08  4.321E-12 -3.000E-16  4.978E+01
    2.896E-02  7.519E-02  4.488E-05  1.453E-07 -2.077E-10  7.868E-14
    6.119E+01  1.807E-01

N2O
    1.075E-01  6.420E-05 -2.626E-08  4.831E-12 -3.309E-16  1.854E+02
   -3.897E-02  5.950E-02  1.964E-04 -1.548E-07  5.061E-11 -1.832E-15
    1.990E+02  2.096E-01

N2
    1.034E-01  5.410E-05 -2.043E-08  3.563E-12 -2.328E-16 -3.234E+01
    2.199E-01  1.312E-01 -4.313E-05  8.296E-08 -2.257E-11 -8.059E-15
   -3.788E+01  8.418E-02

CH4
    9.367E-02  6.493E-04 -2.442E-07  4.225E-11 -2.760E-15 -6.220E+02
    6.674E-01  2.385E-01 -2.480E-04  1.531E-06 -1.417E-09  4.340E-13
   -6.324E+02  5.404E-02

O2
    1.132E-01  2.301E-05 -6.142E-09  1.131E-12 -9.046E-17 -3.756E+01
    1.130E-01  1.133E-01 -5.870E-05  2.205E-07 -2.114E-10  6.736E-14
   -3.274E+01  1.345E-01
```

CO

1.065E-01	5.316E-05	-2.067E-08	3.700E-12	-2.476E-16	-5.086E+02
2.266E-01	1.325E-01	-5.780E-05	1.318E-07	-7.254E-11	8.552E-15
-5.125E+02	1.055E-01				

CO2

1.014E-01	7.040E-05	-2.816E-08	5.167E-12	-3.528E-16	-1.113E+03
-2.241E-02	5.455E-02	1.985E-04	-1.501E-07	4.549E-11	1.438E-17
-1.099E+03	2.203E-01				

H

2.480E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.527E+04
-4.565E-01	2.480E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.527E+04	-4.565E-01				

H2

1.538E+00	2.536E-04	2.611E-08	-1.732E-11	1.833E-15	-4.352E+02
-9.737E-01	1.517E+00	1.328E-03	-2.882E-06	2.739E-09	-8.990E-13
-4.905E+02	-1.141E+00				

H2O

1.508E-01	1.635E-04	-4.453E-08	5.677E-12	-2.691E-16	-1.660E+03
3.681E-01	2.259E-01	-6.153E-05	2.305E-07	-1.645E-10	4.480E-14
-1.681E+03	-1.791E-02				

O

1.589E-01	-1.722E-06	-1.939E-10	2.845E-13	-2.730E-17	1.827E+03
3.075E-01	1.842E-01	-1.024E-04	1.513E-07	-1.002E-10	2.432E-14
1.822E+03	1.853E-01				

OH

1.711E-01	5.641E-05	-1.143E-08	8.089E-13	8.364E-18	2.314E+02
3.200E-01	2.256E-01	-6.338E-05	5.693E-08	1.100E-11	-1.327E-14
2.141E+02	2.903E-02				

REACTION MECHANISM
==================

1. N + NO = N2 + O
2. N + O2 = NO + O
3. OH + N = H + NO
4. H + N2O = OH + N2
5. N2O + O = NO + NO
6. N2O + + M = N2 + O + M
7. N + O + M = NO + + M
8. NO2 + O = NO + O2
9. NO2 + + M = O + NO + M

RATE CONSTANT PARAMETERS
RATE CONSTANT = A*T**B*EXP(-TACT/T) (T=TEMPERATURE)

	FORWARD RATE			BACKWARD RATE		
	A	B	TACT	A	B	TACT
1.	1.500E+10	0.000E+00	0.000E+00	6.753E+10	0.000E+00	3.786E+04
2.	5.998E+06	1.000E+00	3.172E+03	5.857E+09	0.000E+00	2.087E+04
3.	5.998E+08	5.000E-01	4.028E+03	1.102E+11	0.000E+00	2.898E+04
4.	7.998E+10	0.000E+00	7.553E+03	3.842E+09	0.000E+00	4.047E+04
5.	1.000E+11	0.000E+00	1.500E+04	2.895E+09	0.000E+00	3.422E+04
6.	1.000E+11	0.000E+00	2.518E+04	2.678E+06	0.000E+00	6.573E+03
7.	6.397E+10	-5.000E-01	0.000E+00	4.600E+12	0.000E+00	7.488E+04
8.	1.000E+10	0.000E+00	3.000E+02	3.186E+09	0.000E+00	2.393E+04
9.	1.099E+13	0.000E+00	3.300E+04	1.532E+08	0.000E+00	-2.950E+03

NX	NY	NXMAX	NYMAX
10	10	25	20

NTDMA	LSWEEP	RSCHEK	CCHECK
3	150	1.00E-02	5.00E-03

FIELD VALUES OF	U			U					
Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	0.00E+00
Y(8)=6.750E-03	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	0.00E+00
Y(7)=4.750E-03	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	0.00E+00
Y(6)=3.750E-03	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	-4.06E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	0.00E+00
Y(3)=1.500E-03	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	5.68E+00	0.00E+00
Y(2)=5.000E-04	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	0.00E+00
Y(1)=0.000E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	3.18E+00	0.00E+00
XU(IX)	1= 0.000	2= 0.050	3= 0.095	4= 0.145	5= 0.179	6= 0.192	7= 0.200	8= 0.205	9= 0.210

FIELD VALUES OF V ---------- V ----------

YV(9)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
YV(8)=7.375E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.93E+00	-1.66E+00	0.00E+00
YV(7)=5.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.22E+00	-6.25E-01	0.00E+00
YV(6)=4.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.61E-01	5.88E-01	0.00E+00
YV(5)=3.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.39E+00	0.00E+00
YV(4)=3.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.57E+00	0.00E+00
YV(3)=2.125E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E+00	0.00E+00
YV(2)=1.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.18E-01	0.00E+00
YV(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF ENTH ----------ENTH----------

Y(10)=9.000E-03	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02
Y(9)=8.000E-03	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	2.75E+02
Y(8)=6.750E-03	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	2.75E+02
Y(7)=4.750E-03	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	2.75E+02
Y(6)=3.750E-03	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	-1.99E+05	2.75E+02
Y(5)=3.250E-03	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02
Y(4)=2.750E-03	-2.34E+04	-2.34E+04	-2.34E+04	-2.34E+04	-2.34E+04	-2.34E+04	-2.34E+04	-2.34E+04	-2.34E+04	2.75E+02
Y(3)=1.500E-03	-2.34E+04	-2.34E+04	-2.34E+04	-2.34E+04	-2.34E+04	-2.34E+04	-2.34E+04	-2.34E+04	-2.34E+04	2.75E+02
Y(2)=5.000E-04	-4.72E+06	-4.72E+06	-4.72E+06	-4.72E+06	-4.72E+06	-4.72E+06	-4.72E+06	-4.72E+06	-4.72E+06	2.75E+02
Y(1)=0.000E+00	-4.72E+06	-4.72E+06	-4.72E+06	-4.72E+06	-4.72E+06	-4.72E+06	-4.72E+06	-4.72E+06	-4.72E+06	2.75E+02
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF FM ---------- FM ----------

Y(10)=9.000E-03	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	0.00E+00
Y(9)=8.000E-03	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	0.00E+00
Y(8)=6.750E-03	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	0.00E+00
Y(7)=4.750E-03	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	0.00E+00
Y(6)=3.750E-03	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00
Y(1)=0.000E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF FUEL ----------FUEL----------

Y(10)=9.000E-03	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	3.74E-02	3.74E-02	0.00E+00
Y(9)=8.000E-03	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	3.74E-02	3.74E-02	0.00E+00
Y(8)=6.750E-03	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	3.74E-02	3.74E-02	0.00E+00
Y(7)=4.750E-03	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	3.74E-02	3.74E-02	0.00E+00
Y(6)=3.750E-03	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	3.74E-02	3.74E-02	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00
Y(1)=0.000E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF N ---------- N ----------

Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	1.00E-20	1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	1.00E-20	1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	1.00E-20	1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	1.00E-20	1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF NO ---------- NO ----------

Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-15	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-15	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-15	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-15	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-15	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	1.00E-15	1.00E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	1.00E-15	1.00E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	1.00E-15	1.00E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	1.00E-15	1.00E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF NO2 ---------- NO2 ----------

Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	1.00E-20	1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	1.00E-20	1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	1.00E-20	1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	1.00E-20	1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF N2O ---------- N2O ----------

Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-20	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	1.00E-20	1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	1.00E-20	1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	1.00E-20	1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	1.00E-20	1.00E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF N2 ---------- N2 ----------

Y(10)=9.000E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	0.00E+00
Y(9)=8.000E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	0.00E+00
Y(8)=6.750E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	0.00E+00
Y(7)=4.750E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	0.00E+00
Y(6)=3.750E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	7.68E-01	7.68E-01	7.68E-01	7.68E-01	7.68E-01	7.68E-01	7.68E-01	7.68E-01	7.68E-01	0.00E+00
Y(3)=1.500E-03	7.68E-01	7.68E-01	7.68E-01	7.68E-01	7.68E-01	7.68E-01	7.68E-01	7.68E-01	7.68E-01	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF F ---------- F ----------

Y(10)=9.000E-03	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	3.74E-02	3.74E-02	0.00E+00
Y(9)=8.000E-03	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	3.74E-02	3.74E-02	0.00E+00
Y(8)=6.750E-03	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	3.74E-02	3.74E-02	0.00E+00
Y(7)=4.750E-03	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	3.74E-02	3.74E-02	0.00E+00
Y(6)=3.750E-03	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	3.74E-02	3.74E-02	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00
Y(1)=0.000E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF O_2 ---------- O2 ----------

Y(10)=9.000E-03	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	2.23E-01	2.23E-01	0.00E+00
Y(9)=8.000E-03	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	2.23E-01	2.23E-01	0.00E+00
Y(8)=6.750E-03	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	2.23E-01	2.23E-01	0.00E+00
Y(7)=4.750E-03	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	2.23E-01	2.23E-01	0.00E+00
Y(6)=3.750E-03	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	7.36E-02	2.23E-01	2.23E-01	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	2.32E-01	2.32E-01	2.32E-01	2.32E-01	2.32E-01	2.32E-01	2.32E-01	2.32E-01	2.32E-01	0.00E+00
Y(3)=1.500E-03	2.32E-01	2.32E-01	2.32E-01	2.32E-01	2.32E-01	2.32E-01	2.32E-01	2.32E-01	2.32E-01	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF CO ---------- CO ----------

Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF CO_2 ---------- CO2----------

Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF H ---------- H ----------

Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF H_2 ---------- H_2 ----------

Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF H_2O ---------- H_2O ----------

Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF O ---------- O ----------

Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF OH ---------- OH ----------

Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF PR ---------- PR ----------

Y(10)=9.000E-03	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	1.87E-01	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF TEM ---------- TEM ----------

Y(10)=9.000E-03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	2.75E+02	2.75E+02	2.75E+02
Y(9)=8.000E-03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	2.75E+02	2.75E+02	2.75E+02
Y(8)=6.750E-03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	2.75E+02	2.75E+02	2.75E+02
Y(7)=4.750E-03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	2.75E+02	2.75E+02	2.75E+02
Y(6)=3.750E-03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	1.64E+03	2.75E+02	2.75E+02	2.75E+02
Y(5)=3.250E-03	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02
Y(4)=2.750E-03	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02
Y(3)=1.500E-03	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02
Y(2)=5.000E-04	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02
Y(1)=0.000E+00	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02	2.75E+02

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF P ---------- P ----------

Y(9)=8.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(8)=6.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(7)=4.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(6)=3.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(4)=2.750E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(3)=1.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(2)=5.000E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

X(IX) 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207

FIELD VALUES OF RHO ---------- RHO ----------

Y(10)=9.000E-03	2.54E+00	2.54E+00	2.54E+00	2.54E+00	2.54E+00	2.54E+00	2.54E+00	2.54E+00	2.54E+00	2.54E+00
Y(9)=8.000E-03	4.16E-01	4.16E-01	4.16E-01	4.16E-01	4.16E-01	4.16E-01	4.16E-01	2.45E+00	2.45E+00	2.54E+00
Y(8)=6.750E-03	4.16E-01	4.16E-01	4.16E-01	4.16E-01	4.16E-01	4.16E-01	4.16E-01	2.45E+00	2.45E+00	2.54E+00
Y(7)=4.750E-03	4.16E-01	4.16E-01	4.16E-01	4.16E-01	4.16E-01	4.16E-01	4.16E-01	2.45E+00	2.45E+00	2.54E+00
Y(6)=3.750E-03	4.16E-01	4.16E-01	4.16E-01	4.16E-01	4.16E-01	4.16E-01	4.16E-01	2.45E+00	2.45E+00	2.54E+00
Y(5)=3.250E-03	2.45E+00	2.45E+00	2.45E+00	2.45E+00	2.45E+00	2.45E+00	2.45E+00	2.45E+00	2.45E+00	2.54E+00
Y(4)=2.750E-03	2.52E+00	2.52E+00	2.52E+00	2.52E+00	2.52E+00	2.52E+00	2.52E+00	2.52E+00	2.52E+00	2.54E+00
Y(3)=1.500E-03	2.52E+00	2.52E+00	2.52E+00	2.52E+00	2.52E+00	2.52E+00	2.52E+00	2.52E+00	2.52E+00	2.54E+00
Y(2)=5.000E-04	1.40E+00	1.40E+00	1.40E+00	1.40E+00	1.40E+00	1.40E+00	1.40E+00	1.40E+00	1.40E+00	2.54E+00
Y(1)=0.000E+00	1.40E+00	1.40E+00	1.40E+00	1.40E+00	1.40E+00	1.40E+00	1.40E+00	1.40E+00	1.40E+00	2.54E+00

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

FIELD VALUES OF I =1 ---------- I =10----------

Y(10)=9.000E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(9)=8.000E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(8)=6.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(7)=4.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(6)=3.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(5)=3.250E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(4)=2.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(3)=1.500E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(2)=5.000E-04	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(1)=0.000E+00	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03

X(IX) 1= 0.000 2= 0.030 3= 0.070 4= 0.120 5= 0.170 6= 0.188 7= 0.197 8= 0.202 9= 0.207 10= 0.210

SUB OF ABS. VALUES OF RESIDUE(IX,JPHI)-

ISWEEP	U	V	ENTH	FM	FUEL	PP
1	1.91E+01	2.01E+00	2.02E+00	3.50E-03	5.69E-02	1.15E+01
2	3.15E+00	6.90E-01	1.70E-01	8.10E-05	1.58E-02	4.72E+00
3	7.08E+00	8.66E-01	1.13E-01	8.47E-05	4.42E-02	8.34E+00
4	2.81E-01	3.31E-01	6.15E-02	6.97E-06	2.40E-03	3.91E+00
5	6.68E-02	2.76E-01	2.11E-01	5.28E-05	1.81E-04	2.95E+00
6	1.24E-01	1.09E-01	1.16E-02	1.62E-05	1.02E-03	1.80E+00
7	3.92E-03	7.21E-02	1.33E-02	6.24E-06	5.39E-06	1.18E+00
8	5.74E-02	2.77E-02	1.98E-02	4.12E-06	2.34E-03	8.45E-01
9	8.83E-04	3.53E-02	5.89E-03	1.32E-06	4.41E-06	7.36E-01
10	2.78E-02	2.32E-02	8.10E-03	1.45E-06	3.61E-03	5.44E-01
11	1.11E-03	2.65E-02	3.58E-03	5.91E-07	1.62E-06	5.13E-01
12	1.47E-02	2.58E-02	4.55E-03	9.08E-07	8.18E-03	4.39E-01
13	1.26E-03	1.90E-02	1.04E-02	2.92E-07	6.97E-07	3.55E-01
14	2.44E-02	3.36E-02	6.86E-03	6.56E-07	8.91E-03	5.24E-01
15	1.95E-03	1.37E-02	7.82E-03	3.23E-07	5.28E-07	2.45E-01
16	7.01E-03	1.49E-02	1.10E-02	8.16E-06	9.75E-05	2.68E-01
17	9.69E-04	8.21E-03	1.33E-02	1.49E-07	2.51E-07	1.72E-01
18	7.35E-03	8.42E-03	4.96E-03	8.30E-07	3.90E-04	1.71E-01
19	6.51E-04	7.09E-03	8.24E-03	1.81E-07	2.58E-07	1.35E-01
20	4.53E-03	4.55E-03	2.10E-02	2.17E-06	3.04E-04	1.09E-01
21	2.50E-04	4.82E-03	2.03E-02	1.91E-07	3.68E-07	9.85E-02
22	2.26E-03	2.76E-03	2.30E-02	2.51E-06	1.16E-04	7.61E-02
23	1.97E-04	3.52E-03	5.31E-03	9.84E-08	1.87E-07	7.16E-02
24	1.55E-03	1.70E-03	1.04E-02	1.21E-06	2.11E-04	5.54E-02
25	2.78E-04	2.45E-03	7.05E-03	2.85E-07	3.81E-07	5.38E-02
26	6.93E-04	1.03E-03	6.07E-03	4.42E-07	1.61E-04	4.49E-02
27	1.48E-04	1.88E-03	9.98E-03	2.53E-07	2.23E-07	4.24E-02
28	2.04E-04	6.74E-04	5.25E-03	5.06E-07	9.89E-05	3.48E-02
29	3.19E-06	1.51E-03	1.24E-02	1.23E-07	1.69E-07	3.32E-02
30	1.83E-04	4.52E-04	6.56E-03	5.36E-07	5.39E-05	2.76E-02
31	2.90E-05	1.14E-03	1.37E-02	1.61E-07	1.13E-07	2.62E-02
32	4.84E-05	3.18E-04	8.08E-03	5.83E-07	2.23E-05	2.24E-02
33	6.72E-06	9.20E-04	1.44E-02	6.11E-08	6.78E-08	2.11E-02
34	1.73E-05	2.54E-04	9.01E-03	5.72E-07	1.72E-06	1.85E-02
35	9.09E-06	7.52E-04	1.46E-02	1.41E-07	1.12E-07	1.84E-02
36	2.69E-05	2.01E-04	9.50E-03	1.16E-06	1.03E-05	1.58E-02
37	2.45E-06	6.26E-04	1.46E-02	2.04E-07	1.59E-07	1.62E-02
38	3.44E-05	1.85E-04	9.62E-03	6.55E-07	1.49E-05	1.37E-02
39	1.89E-06	5.21E-04	1.43E-02	1.18E-07	1.13E-07	1.45E-02
40	4.37E-05	1.57E-04	9.59E-03	8.31E-07	2.09E-05	1.20E-02
41	5.00E-06	4.51E-04	1.41E-02	1.98E-07	2.05E-07	1.31E-02
42	5.52E-05	1.50E-04	9.49E-03	8.61E-07	2.34E-05	1.07E-02
43	5.47E-06	3.91E-04	1.37E-02	1.23E-07	8.98E-08	1.19E-02
44	4.64E-05	1.33E-04	1.88E-02	7.74E-07	2.27E-05	9.90E-03
45	2.80E-06	3.35E-04	1.34E-02	1.05E-07	1.36E-07	1.08E-02
46	4.95E-05	1.24E-04	1.86E-02	6.52E-07	2.24E-05	9.12E-03
47	2.50E-06	2.92E-04	1.31E-02	2.46E-07	2.49E-07	9.90E-03
48	5.24E-05	1.18E-04	1.81E-02	6.75E-07	2.28E-05	8.41E-03
49	3.32E-06	2.53E-04	1.27E-02	1.22E-07	8.88E-08	9.08E-03

SWEEP NO. 50 ========== SWEEP No. 50

ALGEBRAIC SUM OF RESIDUAL SOURCES AT EACH LINE--RSLINE(IX,JPHI)

IX	NO. TRAVS	U	V	ENTH	FM	FUEL	PP
2	1	0.00E+00	0.00E+00	-7.01E-04	1.99E-07	4.35E-09	0.00E+00
3	1	0.00E+00	2.75E-06	-1.19E-03	-1.38E-07	7.83E-08	1.90E-04
4	1	0.00E+00	2.30E-06	-1.74E-03	1.99E-07	1.80E-06	2.30E-04
5	1	3.01E-07	1.99E-05	-4.81E-03	-7.64E-08	2.21E-05	9.91E-04
6	1	-4.65E-06	-2.47E-05	-9.05E-03	0.00E+00	9.17E-08	4.94E-03
7	2	-7.06E-06	-5.83E-06	-4.57E-05	1.53E-08	-1.53E-08	7.03E-04
8	2	4.14E-05	-2.34E-05	-3.76E-05	-8.59E-09	1.91E-08	3.09E-04
9	2	0.00E+00	-3.48E-05	-3.29E-05	0.00E+00	-2.01E-08	4.49E-04

VALUES AT MONITORING LOCATION (3, 3)

ISWEEP	U	V	ENTH	FM	FUEL	P
50	6.26E+00	-1.62E-03	-1.65E+05	3.79E-02	3.79E-02	-1.99E+01

ISWEEP	U	V	ENTH	FM	FUEL	PP
50	5.34E-05	1.14E-04	1.76E-02	6.35E-07	2.42E-05	7.82E-03
51	2.20E-06	2.20E-04	1.24E-02	1.39E-07	1.15E-07	8.34E-03
52	4.48E-05	1.08E-04	1.71E-02	6.83E-07	2.32E-05	7.17E-03
53	5.04E-06	1.90E-04	1.20E-02	1.48E-07	1.22E-07	7.71E-03
54	4.66E-05	1.02E-04	1.67E-02	5.76E-07	2.26E-05	6.65E-03
55	4.44E-06	1.67E-04	1.17E-02	1.46E-07	1.75E-07	7.13E-03
56	4.54E-05	1.03E-04	1.62E-02	5.75E-07	2.19E-05	6.32E-03
57	9.91E-07	1.43E-04	1.14E-02	1.55E-07	2.03E-07	6.58E-03
58	4.66E-05	1.08E-04	1.58E-02	4.73E-07	2.15E-05	6.04E-03
59	3.14E-06	1.27E-04	1.10E-02	1.11E-07	1.86E-07	6.13E-03
60	4.77E-05	1.04E-04	1.53E-02	3.26E-07	1.98E-05	5.73E-03
61	2.80E-06	1.12E-04	1.08E-02	1.12E-07	7.26E-08	5.74E-03
62	4.34E-05	9.44E-05	1.48E-02	1.49E-06	1.83E-05	5.38E-03
63	2.58E-06	1.02E-04	1.04E-02	1.65E-07	1.77E-07	5.35E-03
64	4.28E-05	9.20E-05	1.45E-02	3.93E-07	2.16E-05	5.14E-03
65	2.45E-06	9.18E-05	1.02E-02	2.19E-07	2.06E-07	5.04E-03
66	4.01E-05	8.48E-05	1.40E-02	7.96E-07	1.90E-05	4.82E-03
67	4.69E-06	8.46E-05	9.88E-03	1.50E-07	1.18E-07	4.71E-03
68	4.33E-05	8.50E-05	1.36E-02	8.20E-07	1.92E-05	4.56E-03
69	3.19E-06	7.35E-05	9.57E-03	1.73E-07	1.76E-07	4.42E-03
70	3.78E-05	7.62E-05	1.32E-02	5.88E-07	1.74E-05	4.30E-03
71	3.23E-06	6.97E-05	9.32E-03	2.24E-07	2.31E-07	4.10E-03
72	3.43E-05	6.86E-05	1.29E-02	6.93E-07	1.87E-05	4.02E-03
73	2.71E-06	6.45E-05	9.08E-03	2.47E-07	2.03E-07	3.88E-03
74	3.65E-05	7.43E-05	1.25E-02	7.95E-07	1.68E-05	3.90E-03
75	4.91E-06	5.63E-05	8.82E-03	7.54E-08	1.04E-07	3.61E-03
76	3.60E-05	7.40E-05	1.22E-02	9.35E-07	1.70E-05	3.76E-03
77	2.37E-06	4.98E-05	8.52E-03	7.54E-08	6.88E-08	3.41E-03
78	3.46E-05	6.30E-05	1.18E-02	5.26E-07	1.49E-05	3.55E-03
79	2.28E-06	4.55E-05	8.31E-03	1.33E-07	1.77E-07	3.19E-03
80	3.64E-05	6.98E-05	1.15E-02	2.34E-07	1.57E-05	3.43E-03
81	5.34E-06	4.33E-05	8.07E-03	1.40E-07	1.16E-07	2.90E-03
82	2.88E-05	6.58E-05	1.11E-02	8.71E-07	1.49E-05	3.26E-03
83	1.64E-06	3.70E-05	7.86E-03	2.10E-07	2.17E-07	2.78E-03
84	3.44E-05	6.80E-05	1.08E-02	4.21E-07	1.52E-05	2.97E-03
85	9.91E-07	3.74E-05	7.66E-03	2.46E-07	2.66E-07	2.65E-03
86	3.05E-05	6.13E-05	1.05E-02	1.09E-06	1.57E-05	2.82E-03
87	4.91E-06	3.56E-05	7.41E-03	1.38E-07	1.66E-07	2.54E-03
88	3.34E-05	6.22E-05	1.02E-02	7.38E-07	1.30E-05	2.62E-03
89	3.27E-06	4.54E-05	1.71E-02	3.28E-07	3.31E-07	2.44E-03
90	3.33E-05	5.79E-05	9.93E-03	7.53E-07	1.34E-05	2.47E-03
91	2.89E-06	3.96E-05	1.66E-02	8.02E-08	4.68E-08	2.35E-03
92	3.24E-05	6.34E-05	9.65E-03	6.18E-07	1.26E-05	2.39E-03
93	5.68E-06	5.05E-05	2.61E-02	2.94E-07	2.97E-07	2.28E-03
94	3.80E-05	5.79E-05	1.91E-02	8.47E-07	1.41E-05	2.26E-03
95	4.91E-06	4.83E-05	2.54E-02	2.65E-07	2.54E-07	2.20E-03
96	2.90E-05	5.22E-05	1.87E-02	1.03E-06	1.02E-05	2.09E-03
97	3.57E-06	4.71E-05	2.47E-02	2.09E-07	1.73E-07	2.11E-03
98	2.86E-05	4.62E-05	2.78E-02	8.42E-07	1.11E-05	1.91E-03
99	3.92E-06	4.71E-05	2.40E-02	2.24E-07	1.71E-07	2.04E-03

SWEEP NO. 100 ========== SWEEP No. 100

ALGEBRAIC SUM OF RESIDUAL SOURCES AT EACH LINE--RSLINE(IX,JPHI)

IX	NO. TRAVS	U	V	ENTH	FM	FUEL	PP
2	1	-6.89E-07	0.00E+00	-3.47E-04	-1.53E-08	2.17E-09	0.00E+00
3	1	0.00E+00	1.63E-06	-5.81E-04	4.58E-08	3.86E-08	4.95E-05
4	1	-1.38E-06	4.02E-06	-8.49E-04	-2.60E-07	8.54E-07	7.19E-05
5	1	6.89E-07	3.99E-06	-2.34E-03	-7.64E-08	1.06E-05	2.31E-04
6	1	-4.74E-07	-1.59E-06	-4.42E-03	4.58E-08	3.06E-08	8.64E-04
7	1	-1.65E-06	6.86E-06	-9.07E-03	3.06E-08	1.53E-08	2.53E-04
8	1	1.92E-05	-1.02E-05	-9.49E-03	-2.48E-08	-3.25E-08	2.29E-04
9	2	0.00E+00	-1.55E-05	-1.69E-05	-1.62E-08	2.77E-08	1.35E-04

VALUES AT MONITORING LOCATION (5, 3)

ISWLFP	U	V	ENTH	FM	FUEL	P
100	6.26E+00	-1.62E-03	-1.65E+05	3.79E-02	3.79E-02	-1.99E+01

ISWEEP	U	V	EPSTH	FM	FUEL	PP
100	2.40E-05	4.38E-05	2.71E-02	5.15E-07	1.17E-05	1.83E-03
101	4.01E-06	4.42E-05	2.33E-02	1.62E-07	1.41E-07	1.98E-03
102	2.37E-05	5.42E-05	2.63E-02	8.89E-07	1.11E-05	1.90E-03
103	4.18E-06	4.68E-05	2.27E-02	4.26E-07	3.46E-07	1.97E-03
104	2.31E-05	5.86E-05	2.56E-02	9.69E-07	1.24E-05	1.91E-03
105	4.26E-06	4.94E-05	2.20E-02	1.24E-07	1.34E-07	1.92E-03
106	1.84E-05	5.25E-05	2.49E-02	4.54E-07	1.06E-05	1.81E-03
107	5.08E-06	4.84E-05	2.14E-02	1.59E-07	2.08E-07	1.87E-03
108	2.57E-05	4.86E-05	2.42E-02	8.01E-07	1.03E-05	1.71E-03
109	4.65E-06	4.96E-05	2.08E-02	1.96E-07	2.54E-07	1.82E-03
110	2.45E-05	5.36E-05	2.35E-02	4.01E-07	1.03E-05	1.70E-03
111	4.13E-06	4.75E-05	2.02E-02	2.36E-07	1.54E-07	1.78E-03
112	2.34E-05	5.47E-05	2.28E-02	5.38E-07	9.16E-06	1.67E-03
113	2.15E-06	4.94E-05	1.96E-02	1.52E-07	1.55E-07	1.75E-03
114	2.58E-05	5.16E-05	2.21E-02	8.40E-07	9.76E-06	1.62E-03
115	3.45E-06	4.63E-05	1.91E-02	2.01E-07	1.65E-07	1.69E-03
116	2.08E-05	5.30E-05	2.15E-02	3.63E-07	9.26E-06	1.59E-03
117	3.23E-06	4.63E-05	1.85E-02	3.24E-07	2.78E-07	1.65E-03
118	1.55E-05	5.23E-05	2.09E-02	4.83E-07	8.91E-06	1.52E-03
119	4.87E-06	4.41E-05	1.79E-02	1.47E-07	1.31E-07	1.61E-03
120	1.87E-05	5.98E-05	2.03E-02	6.01E-07	9.52E-06	1.54E-03
121	5.51E-06	4.76E-05	1.75E-02	1.11E-07	1.68E-07	1.60E-03
122	2.03E-05	5.69E-05	1.97E-02	5.62E-07	9.17E-06	1.53E-03
123	2.67E-06	4.46E-05	1.70E-02	1.47E-07	9.65E-08	1.56E-03
124	1.85E-05	4.63E-05	1.91E-02	6.76E-07	9.01E-06	1.37E-03
125	2.58E-06	4.52E-05	1.65E-02	1.30E-07	1.44E-07	1.53E-03
126	1.78E-05	4.63E-05	1.86E-02	1.06E-06	6.91E-06	1.35E-03
127	5.38E-06	4.04E-05	1.60E-02	2.23E-07	2.44E-07	1.48E-03
128	1.71E-05	4.65E-05	1.80E-02	5.76E-07	9.54E-06	1.34E-03
129	3.32E-06	4.08E-05	1.55E-02	3.37E-07	2.76E-07	1.45E-03
130	1.79E-05	4.71E-05	1.75E-02	7.53E-07	7.17E-06	1.21E-03
131	3.92E-06	4.16E-05	1.51E-02	3.89E-07	2.71E-07	1.42E-03
132	2.27E-05	3.97E-05	1.70E-02	9.38E-07	6.78E-06	1.14E-03
133	5.21E-06	4.05E-05	1.46E-02	1.75E-07	1.68E-07	1.35E-03
134	1.65E-05	3.40E-05	1.65E-02	5.60E-07	7.13E-06	1.10E-03
135	3.92E-06	3.56E-05	1.42E-02	9.07E-08	1.99E-07	1.29E-03
136	1.56E-05	3.39E-05	1.60E-02	6.47E-07	6.85E-06	1.09E-03
137	3.66E-06	3.55E-05	1.38E-02	3.43E-07	2.93E-07	1.28E-03
138	1.51E-05	3.49E-05	1.56E-02	7.02E-07	7.58E-06	1.03E-03
139	3.92E-06	3.25E-05	1.34E-02	1.00E-07	9.74E-08	1.25E-03
140	1.72E-05	3.92E-05	1.51E-02	4.18E-07	6.27E-06	1.06E-03
141	5.08E-06	3.54E-05	1.30E-02	3.85E-07	1.97E-07	1.19E-03
142	1.63E-05	3.69E-05	1.47E-02	3.33E-07	6.08E-06	1.03E-03
143	4.22E-06	3.34E-05	2.26E-02	2.10E-07	2.21E-07	1.16E-03
144	4.82E-06	2.20E-05	2.42E-02	9.81E-07	7.14E-06	9.67E-04
145	4.31E-06	2.81E-05	2.20E-02	1.37E-07	1.61E-07	1.10E-03
146	4.35E-06	2.84E-05	2.35E-02	7.10E-07	4.94E-06	9.91E-04
147	4.65E-06	2.86E-05	2.14E-02	1.04E-07	6.97E-08	1.10E-03
148	3.23E-05	2.72E-05	2.29E-02	5.06E-07	6.80E-06	9.36E-04
149	5.25E-06	2.86E-05	2.07E-02	2.75E-07	2.81E-07	1.10E-03

SWEEP NO. 150 ========== SWEEP NO. 150

ALGEBRAIC SUM OF RESIDUAL SOURCES AT EACH LINE--RSLINE(IX,JPHI)

IX	NO. TRAVS	U	V	ENTH	FM	FUEL	PP
2	1	-6.89E-07	0.00E+00	-1.65E-04	-1.07E-07	7.48E-10	0.00E+00
3	1	-6.89E-07	-6.26E-06	-2.75E-04	-2.44E-07	1.45E-08	6.47E-05
4	1	0.00E+00	2.07E-06	-4.13E-04	3.21E-07	3.55E-07	6.56E-05
5	1	-2.15E-07	-1.42E-06	-1.13E-03	3.06E-08	4.76E-06	2.65E-05
6	1	-5.17E-07	6.20E-07	-2.13E-03	0.00E+00	4.58E-08	2.16E-04
7	1	-1.46E-06	5.51E-06	-4.38E-03	0.00E+00	4.58E-08	2.99E-04
8	1	1.21E-06	-1.19E-05	-4.58E-03	1.15E-08	1.53E-08	1.81E-04
9	1	0.00E+00	-5.93E-06	-9.15E-03	3.25E-08	1.24E-08	1.06E-04

VALUES AT MONITORING LOCATION (3, 3)

ISWEEP	U	V	ENTH	FM	FUEL	P
150	6.26E+00	-1.63E-03	-1.65E+05	3.79E-02	3.79E-02	-1.99E+01

SUM OF ABS. VALUES OF RSLINE(IX,JPHI)-

ISWEEP	U	V	ENTH	FM	FUEL	PP
150	4.77E-06	3.37E-05	2.22E-02	7.47E-07	5.25E-06	9.59E-04

FIELD VALUES OF U ---------- U ----------

Y(10)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Y(9)=8.000E-03	-4.51E+00	-4.51E+00	-4.62E+00	-4.59E+00	-1.12E+00	-1.07E+00	-1.56E+00	-2.23E+00	0.00E+00
Y(8)=6.750E-03	-4.51E+00	-4.51E+00	-4.62E+00	-4.60E+00	-1.10E+00	-9.28E-01	-8.85E-01	-9.75E-01	0.00E+00
Y(7)=4.750E-03	-4.35E+00	-4.35E+00	-4.45E+00	-4.44E+00	-1.05E+00	-6.96E-01	-9.04E-02	9.14E-01	0.00E+00
Y(6)=3.750E-03	-4.17E+00	-4.17E+00	-4.24E+00	-4.22E+00	-1.01E+00	-6.27E-01	9.10E-02	2.33E+00	0.00E+00
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.33E-17	3.27E+00	0.00E+00
Y(4)=2.750E-03	5.68E+00	5.67E+00	5.97E+00	6.29E+00	6.49E+00	6.52E+00	6.56E+00	4.24E+00	0.00E+00
Y(3)=1.500E-03	5.68E+00	5.89E+00	6.26E+00	6.64E+00	6.75E+00	6.80E+00	6.80E+00	4.99E+00	0.00E+00
Y(2)=5.000E-04	3.18E+00	5.93E+00	6.36E+00	6.77E+00	6.86E+00	6.91E+00	6.89E+00	5.20E+00	0.00E+00
Y(1)=0.000E+00	3.18E+00	5.93E+00	6.36E+00	6.77E+00	6.86E+00	6.91E+00	6.89E+00	5.20E+00	0.00E+00
XU(IX)	1= 0.000	2= 0.050	3= 0.095	4= 0.145	5= 0.179	6= 0.192	7= 0.200	8= 0.205	9= 0.210

FIELD VALUES OF V ---------- V ----------

YV(9)=9.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
YV(8)=7.375E-03	0.00E+00	-4.98E-24	-1.50E-04	1.17E-04	-4.18E-03	-2.15E-02	-1.24E-01	-2.47E-01	8.03E-01	0.00E+00
YV(7)=5.750E-03	0.00E+00	-6.53E-24	-4.09E-04	-1.14E-05	-5.34E-03	-2.87E-02	-1.52E-01	-3.52E-01	1.39E+00	0.00E+00
YV(6)=4.250E-03	0.00E+00	-2.86E-24	-3.23E-04	-1.95E-04	-1.37E-03	-1.24E-02	-6.54E-02	-1.20E-01	1.55E+00	0.00E+00
YV(5)=3.500E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.27E-01	1.50E+00	0.00E+00
YV(4)=3.000E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.17E-01	1.39E+00	0.00E+00
YV(3)=2.125E-03	0.00E+00	-1.29E-02	-1.63E-03	-5.28E-04	2.16E-03	1.77E-07	4.34E-03	3.81E-01	1.07E+00	0.00E+00
YV(2)=1.000E-03	0.00E+00	-3.89E-02	-2.44E-03	-4.82E-04	1.47E-03	1.57E-04	3.11E-03	1.70E-01	5.21E-01	0.00E+00
YV(1)=0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF ENTH ----------ENTH----------

Y(10)=9.000E-03	6.38E+02	6.38E+02	7.38E+02	7.63E+02	6.86E+02	6.45E+02	6.29E+02	6.23E+02	6.20E+02	6.19E+02
Y(9)=8.000E-03	-3.36E+05	-3.36E+05	-2.70E+05	-2.13E+05	-1.48E+05	-1.19E+05	-1.20E+05	-1.23E+05	-1.25E+05	6.18E+02
Y(8)=6.750E-03	-3.33E+05	-3.33E+05	-2.67E+05	-2.10E+05	-1.47E+05	-1.20E+05	-1.21E+05	-1.24E+05	-1.26E+05	6.18E+02
Y(7)=4.750E-03	-3.33E+05	-3.33E+05	-2.68E+05	-2.10E+05	-1.47E+05	-1.20E+05	-1.21E+05	-1.24E+05	-1.26E+05	6.18E+02
Y(6)=3.750E-03	-3.35E+05	-3.35E+05	-2.71E+05	-2.13E+05	-1.49E+05	-1.20E+05	-1.21E+05	-1.25E+05	-1.27E+05	6.18E+02
Y(5)=3.250E-03	4.69E+02	4.89E+02	5.11E+02	5.21E+02	4.54E+02	4.12E+02	4.04E+02	-1.26E+05	-1.28E+05	6.18E+02
Y(4)=2.750E-03	-2.34E+04	-1.42E+05	-1.52E+05	-1.37E+05	-1.31E+05	-1.29E+05	-1.28E+05	-1.28E+05	-1.28E+05	6.18E+02
Y(3)=1.500E-03	-2.34E+04	-1.84E+05	-1.65E+05	-1.43E+05	-1.34E+05	-1.32E+05	-1.30E+05	-1.30E+05	-1.29E+05	6.17E+02
Y(2)=5.000E-04	-4.72E+06	-3.17E+05	-1.80E+05	-1.47E+05	-1.36E+05	-1.33E+05	-1.31E+05	-1.31E+05	-1.30E+05	6.17E+02
Y(1)=0.000E+00	-4.72E+06	-3.17E+05	-1.80E+05	-1.47E+05	-1.36E+05	-1.33E+05	-1.31E+05	-1.31E+05	-1.30E+05	6.17E+02
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF FR ----------FR----------

Y(10)=9.000E-03	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02
Y(9)=8.000E-03	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02
Y(8)=6.750E-03	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02
Y(7)=4.750E-03	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02
Y(6)=3.750E-03	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.72E-02	3.71E-02	3.71E-02	3.72E-02	3.72E-02
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-02	3.72E-02	3.72E-02
Y(4)=2.750E-03	0.00E+00	3.01E-02	3.62E-02	3.73E-02	3.74E-02	3.74E-02	3.74E-02	3.72E-02	3.73E-02	3.73E-02
Y(3)=1.500E-03	0.00E+00	3.82E-02	3.79E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.73E-02	3.73E-02
Y(2)=5.000E-04	1.00E+00	6.65E-02	4.07E-02	3.78E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02
Y(1)=0.000E+00	1.00E+00	6.65E-02	4.07E-02	3.78E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF FUEL ----------FUEL----------

Y(10)=9.000E-03	9.13E-08	9.13E-08	1.85E-06	4.55E-05	1.56E-03	3.57E-02	3.71E-02	3.71E-02	3.72E-02	3.72E-02
Y(9)=8.000E-03	9.13E-08	9.13E-08	1.85E-06	4.55E-05	1.56E-03	3.57E-02	3.71E-02	3.71E-02	3.72E-02	3.72E-02
Y(8)=6.750E-03	8.89E-08	8.89E-08	1.80E-06	4.44E-05	1.52E-03	3.56E-02	3.70E-02	3.71E-02	3.72E-02	3.72E-02
Y(7)=4.750E-03	8.28E-08	8.28E-08	1.67E-06	4.13E-05	1.44E-03	3.55E-02	3.70E-02	3.71E-02	3.72E-02	3.72E-02
Y(6)=3.750E-03	8.11E-08	8.11E-08	1.63E-06	4.02E-05	1.41E-03	3.55E-02	3.70E-02	3.70E-02	3.72E-02	3.72E-02
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-02	3.72E-02	3.72E-02
Y(4)=2.750E-03	0.00E+00	3.01E-02	3.62E-02	3.73E-02	3.74E-02	3.74E-02	3.74E-02	3.72E-02	3.72E-02	3.72E-02
Y(3)=1.500E-03	0.00E+00	3.82E-02	3.79E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.73E-02	3.73E-02
Y(2)=5.000E-04	1.00E+00	6.65E-02	4.07E-02	3.78E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02
Y(1)=0.000E+00	1.00E+00	6.65E-02	4.07E-02	3.78E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF H

Y(10)=9.000E-03	9.45E-15	9.45E-15	2.91E-14	7.25E-14	5.18E-14	2.28E-15	1.49E-16	2.52E-17	1.57E-17	1.57E-17
Y(9)=8.000E-03	9.45E-15	9.45E-15	2.91E-14	7.25E-14	5.18E-14	2.28E-15	1.49E-16	2.52E-17	1.57E-17	1.57E-17
Y(8)=6.750E-03	9.97E-15	9.97E-15	3.05E-14	7.59E-14	5.49E-14	2.37E-15	1.74E-16	2.86E-17	1.53E-17	1.53E-17
Y(7)=4.750E-03	9.97E-15	9.97E-15	3.04E-14	7.58E-14	5.90E-14	2.56E-15	2.31E-16	3.23E-17	1.48E-17	1.48E-17
Y(6)=3.750E-03	9.48E-15	9.48E-15	2.89E-14	7.23E-14	5.86E-14	2.60E-15	2.47E-16	2.47E-17	1.18E-17	1.18E-17
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.50E-17	9.12E-18	9.12E-18
Y(4)=2.750E-03	0.00E+00	6.41E-32	2.55E-29	1.24E-26	6.07E-24	1.11E-21	1.24E-19	7.38E-18	6.78E-18	6.78E-18
Y(3)=1.500E-03	0.00E+00	6.49E-32	2.52E-29	1.22E-26	5.80E-24	9.15E-22	7.31E-20	2.23E-18	3.60E-18	3.60E-18
Y(2)=5.000E-04	0.00E+00	6.83E-32	2.51E-29	1.21E-26	5.63E-24	8.10E-22	5.28E-20	1.15E-18	2.54E-18	2.54E-18
Y(1)=0.000E+00	0.00E+00	6.83E-32	2.51E-29	1.21E-26	5.63E-24	8.10E-22	5.28E-20	1.15E-18	2.54E-18	2.54E-18
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF NO

Y(10)=9.000E-03	4.18E-06	4.18E-06	4.83E-06	4.38E-06	1.82E-06	7.70E-08	4.95E-09	8.24E-10	5.08E-10	5.08E-10
Y(9)=8.000E-03	4.18E-06	4.18E-06	4.83E-06	4.38E-06	1.82E-06	7.70E-08	4.95E-09	8.24E-10	5.08E-10	5.08E-10
Y(8)=6.750E-03	4.13E-06	4.13E-06	4.81E-06	4.39E-06	1.85E-06	7.94E-08	5.75E-09	9.32E-10	4.96E-10	4.96E-10
Y(7)=4.750E-03	4.06E-06	4.06E-06	4.79E-06	4.44E-06	1.93E-06	8.51E-08	7.61E-09	1.05E-09	4.79E-10	4.79E-10
Y(6)=3.750E-03	4.01E-06	4.01E-06	4.77E-06	4.45E-06	1.96E-06	8.64E-08	8.11E-09	8.03E-10	3.81E-10	3.81E-10
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.88E-10	2.94E-10	2.94E-10
Y(4)=2.750E-03	0.00E+00	1.71E-24	7.24E-22	3.69E-19	1.89E-16	3.52E-14	4.00E-12	2.39E-10	2.18E-10	2.18E-10
Y(3)=1.500E-03	0.00E+00	1.70E-24	7.10E-22	3.60E-19	1.79E-16	2.89E-14	2.34E-12	7.18E-11	1.16E-10	1.16E-10
Y(2)=5.000E-04	0.00E+00	1.77E-24	7.00E-22	3.54E-19	1.73E-16	2.55E-14	1.68E-12	3.69E-11	8.13E-11	8.13E-11
Y(1)=0.000E+00	0.00E+00	1.77E-24	7.00E-22	3.54E-19	1.73E-16	2.55E-14	1.68E-12	3.69E-11	8.13E-11	8.13E-11
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF NO2

Y(10)=9.000E-03	2.58E-08	2.58E-08	2.56E-08	2.05E-08	9.48E-09	3.99E-10	2.56E-11	4.26E-12	2.63E-12	2.63E-12
Y(9)=8.000E-03	2.58E-08	2.58E-08	2.56E-08	2.05E-08	9.48E-09	3.99E-10	2.56E-11	4.26E-12	2.63E-12	2.63E-12
Y(8)=6.750E-03	2.52E-08	2.52E-08	2.53E-08	2.05E-08	9.55E-09	4.11E-10	2.97E-11	4.82E-12	2.57E-12	2.57E-12
Y(7)=4.750E-03	2.48E-08	2.48E-08	2.52E-08	2.07E-08	9.84E-09	4.39E-10	3.93E-11	5.45E-12	2.48E-12	2.48E-12
Y(6)=3.750E-03	2.47E-08	2.47E-08	2.52E-08	2.09E-08	1.00E-08	4.45E-10	4.19E-11	4.15E-12	1.97E-12	1.97E-12
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.52E-12	1.52E-12	1.52E-12
Y(4)=2.750E-03	0.00E+00	8.85E-27	3.75E-24	1.91E-21	9.77E-19	1.82E-16	2.07E-14	1.24E-12	1.13E-12	1.13E-12
Y(3)=1.500E-03	0.00E+00	8.85E-27	3.68E-24	1.87E-21	9.27E-19	1.50E-16	1.21E-14	3.71E-13	5.98E-13	5.98E-13
Y(2)=5.000E-04	0.00E+00	9.19E-27	3.62E-24	1.83E-21	8.94E-19	1.32E-16	8.69E-15	1.91E-13	4.20E-13	4.20E-13
Y(1)=0.000E+00	0.00E+00	9.19E-27	3.62E-24	1.83E-21	8.94E-19	1.32E-16	8.69E-15	1.91E-13	4.20E-13	4.20E-13
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF H2O ---------- H2O ----------

Y(10)=9.000E-03	6.44E-09	6.44E-09	8.13E-09	1.01E-08	9.18E-09	3.91E-10	2.54E-11	4.31E-12	2.68E-12	2.68E-12
Y(9)=8.000E-03	6.44E-09	6.44E-09	8.13E-09	1.01E-08	9.10E-09	3.91E-10	2.54E-11	4.31E-12	2.68E-12	2.68E-12
Y(8)=6.750E-03	6.51E-09	6.51E-09	8.22E-09	1.02E-08	9.31E-09	4.03E-10	2.96E-11	4.87E-12	2.62E-12	2.62E-12
Y(7)=4.750E-03	6.51E-09	6.51E-09	8.21E-09	1.02E-08	9.49E-09	4.31E-10	3.92E-11	5.51E-12	2.52E-12	2.52E-12
Y(6)=3.750E-03	6.45E-09	6.45E-09	8.12E-09	1.01E-08	9.47E-09	4.37E-10	4.19E-11	4.21E-12	2.02E-12	2.02E-12
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.56E-12	1.56E-12	1.56E-12
Y(4)=2.750E-03	0.00E+00	1.11E-26	4.40E-24	2.13E-21	1.04E-18	1.89E-16	2.12E-14	1.26E-12	1.16E-12	1.16E-12
Y(3)=1.500E-03	0.00E+00	1.12E-26	4.36E-24	2.10E-21	9.95E-19	1.57E-16	1.25E-14	3.80E-13	6.15E-13	6.15E-13
Y(2)=5.000E-04	0.00E+00	1.19E-26	4.35E-24	2.08E-21	9.66E-19	1.39E-16	9.03E-15	1.96E-13	4.33E-13	4.33E-13
Y(1)=0.000E+00	0.00E+00	1.19E-26	4.35E-24	2.08E-21	9.66E-19	1.39E-16	9.03E-15	1.96E-13	4.33E-13	4.33E-13
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF N2 ---------- N2 ----------

Y(10)=9.000E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01
Y(9)=8.000E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01
Y(8)=6.750E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01
Y(7)=4.750E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.40E-01	7.39E-01	7.39E-01
Y(6)=3.750E-03	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.40E-01	7.39E-01	7.39E-01
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.40E-01	7.39E-01	7.39E-01
Y(4)=2.750E-03	7.60E-01	7.45E-01	7.40E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01
Y(3)=1.500E-03	7.60E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01
Y(2)=5.000E-04	0.00E+00	7.17E-01	7.37E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01
Y(1)=0.000E+00	0.00E+00	7.17E-01	7.37E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01	7.39E-01
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF F ---------- F ----------

Y(10)=9.000E-03	9.13E-08	9.13E-08	1.85E-06	4.55E-05	1.56E-03	3.57E-02	3.71E-02	3.71E-02	3.72E-02	3.72E-02
Y(9)=8.000E-03	9.13E-08	9.13E-08	1.85E-06	4.55E-05	1.56E-03	3.57E-02	3.71E-02	3.71E-02	3.72E-02	3.72E-02
Y(8)=6.750E-03	8.89E-08	8.89E-08	1.80E-06	4.44E-05	1.52E-03	3.56E-02	3.70E-02	3.71E-02	3.72E-02	3.72E-02
Y(7)=4.750E-03	8.28E-08	8.28E-08	1.67E-06	4.13E-05	1.44E-03	3.55E-02	3.70E-02	3.71E-02	3.72E-02	3.72E-02
Y(6)=3.750E-03	8.11E-08	8.11E-08	1.63E-06	4.02E-05	1.41E-03	3.55E-02	3.70E-02	3.70E-02	3.72E-02	3.72E-02
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.70E-02	3.72E-02	3.72E-02
Y(4)=2.750E-03	0.00E+00	3.01E-02	3.62E-02	3.73E-02	3.74E-02	3.74E-02	3.74E-02	3.72E-02	3.72E-02	3.72E-02
Y(3)=1.500E-03	0.00E+00	3.82E-02	3.79E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.73E-02	3.73E-02
Y(2)=5.000E-04	1.00E+00	6.65E-02	4.07E-02	3.78E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02
Y(1)=0.000E+00	1.00E+00	6.65E-02	4.07E-02	3.78E-02	3.75E-02	3.75E-02	3.74E-02	3.74E-02	3.74E-02	3.74E-02
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF O2 ---------- O2 ----------

Y(10)=9.000E-03	7.48E-02	7.48E-02	7.48E-02	7.49E-02	8.10E-02	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(9)=8.000E-03	7.48E-02	7.48E-02	7.48E-02	7.49E-02	8.10E-02	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(8)=6.750E-03	7.48E-02	7.48E-02	7.48E-02	7.49E-02	8.09E-02	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(7)=4.750E-03	7.48E-02	7.48E-02	7.48E-02	7.49E-02	8.05E-02	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(6)=3.750E-03	7.48E-02	7.48E-02	7.48E-02	7.49E-02	8.04E-02	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.23E-01	2.23E-01	2.23E-01
Y(4)=2.750E-03	2.32E-01	2.25E-01	2.24E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(3)=1.500E-03	2.32E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(2)=5.000E-04	0.00E+00	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
Y(1)=0.000E+00	0.00E+00	2.17E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01	2.23E-01
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF CO ---------- CO ----------

Y(10)=9.000E-03	1.13E-05	1.13E-05	1.62E-05	2.20E-05	1.97E-05	4.38E-12	2.85E-13	4.82E-14	2.99E-14	2.99E-14
Y(9)=8.000E-03	1.13E-05	1.13E-05	1.62E-05	2.20E-05	1.97E-05	4.38E-12	2.85E-13	4.82E-14	2.99E-14	2.99E-14
Y(8)=6.750E-03	1.15E-05	1.15E-05	1.65E-05	2.24E-05	2.01E-05	4.51E-12	3.32E-13	5.45E-14	2.92E-14	2.92E-14
Y(7)=4.750E-03	1.15E-05	1.15E-05	1.65E-05	2.24E-05	2.06E-05	4.81E-12	4.39E-13	6.17E-14	2.82E-14	2.82E-14
Y(6)=3.750E-03	1.13E-05	1.13E-05	1.62E-05	2.20E-05	2.05E-05	4.88E-12	4.69E-13	4.70E-14	2.25E-14	2.25E-14
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.86E-14	1.74E-14	1.74E-14
Y(4)=2.750E-03	0.00E+00	5.85E-20	5.85E-20	5.85E-20	5.85E-20	5.85E-20	1.96E-16	1.40E-14	1.29E-14	1.29E-14
Y(3)=1.500E-03	0.00E+00	5.85E-20	5.85E-20	5.85E-20	5.85E-20	5.85E-20	1.20E-16	4.24E-15	6.81E-15	6.81E-15
Y(2)=5.000E-04	0.00E+00	5.85E-20	5.85E-20	5.85E-20	5.85E-20	5.85E-20	7.62E-17	2.17E-15	4.79E-15	4.79E-15
Y(1)=0.000E+00	0.00E+00	5.85E-20	5.85E-20	5.85E-20	5.85E-20	5.85E-20	7.62E-17	2.17E-15	4.79E-15	4.79E-15
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF CO2 ---------- CO2 ----------

Y(10)=9.000E-03	1.02E-01	1.02E-01	1.02E-01	1.02E-01	9.78E-02	4.12E-03	2.68E-04	4.53E-05	2.81E-05	2.81E-05
Y(9)=8.000E-03	1.02E-01	1.02E-01	1.02E-01	1.02E-01	9.78E-02	4.12E-03	2.68E-04	4.53E-05	2.81E-05	2.81E-05
Y(8)=6.750E-03	1.02E-01	1.02E-01	1.02E-01	1.02E-01	9.79E-02	4.25E-03	3.12E-04	5.13E-05	2.75E-05	2.75E-05
Y(7)=4.750E-03	1.02E-01	1.02E-01	1.02E-01	1.02E-01	9.81E-02	4.52E-03	4.13E-04	5.80E-05	2.65E-05	2.65E-05
Y(6)=3.750E-03	1.02E-01	1.02E-01	1.02E-01	1.02E-01	9.82E-02	4.59E-03	4.41E-04	4.42E-05	2.12E-05	2.12E-05
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.69E-05	1.63E-05	1.63E-05
Y(4)=2.750E-03	0.00E+00	5.50E-11	5.50E-11	5.50E-11	5.50E-11	5.50E-11	1.84E-07	1.32E-05	1.21E-05	1.21E-05
Y(3)=1.500E-03	0.00E+00	5.50E-11	5.50E-11	5.50E-11	5.50E-11	5.50E-11	1.13E-07	3.98E-06	6.40E-06	6.40E-06
Y(2)=5.000E-04	0.00E+00	5.50E-11	5.50E-11	5.50E-11	5.50E-11	5.50E-11	7.17E-08	2.04E-06	4.51E-06	4.51E-06
Y(1)=0.000E+00	0.00E+00	5.50E-11	5.50E-11	5.50E-11	5.50E-11	5.50E-11	7.17E-08	2.04E-06	4.51E-06	4.51E-06
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF H ---------- H ----------

Y(10)=9.000E-03	1.92E-09	1.92E-09	3.33E-09	5.29E-09	4.55E-09	3.65E-18	2.37E-19	4.01E-20	2.49E-20	2.49E-20
Y(9)=8.000E-03	1.92E-09	1.92E-09	3.33E-09	5.29E-09	4.55E-09	3.65E-18	2.37E-19	4.01E-20	2.49E-20	2.49E-20
Y(8)=6.750E-03	1.97E-09	1.97E-09	3.41E-09	5.41E-09	4.68E-09	3.75E-18	2.76E-19	4.53E-20	2.43E-20	2.43E-20
Y(7)=4.750E-03	1.97E-09	1.97E-09	3.40E-09	5.41E-09	4.85E-09	4.00E-18	3.65E-19	5.13E-20	2.35E-20	2.35E-20
Y(6)=3.750E-03	1.92E-09	1.92E-09	3.32E-09	5.28E-09	4.83E-09	4.06E-18	3.90E-19	3.91E-20	1.87E-20	1.87E-20
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.38E-20	1.44E-20	1.44E-20
Y(4)=2.750E-03	0.00E+00	4.86E-26	4.86E-26	4.86E-26	4.86E-26	4.86E-26	1.63E-22	1.17E-20	1.07E-20	1.07E-20
Y(3)=1.500E-03	0.00E+00	4.86E-26	4.86E-26	4.86E-26	4.86E-26	4.86E-26	9.96E-23	3.52E-21	5.66E-21	5.66E-21
Y(2)=5.000E-04	0.00E+00	4.86E-26	4.86E-26	4.86E-26	4.86E-26	4.86E-26	6.34E-23	1.80E-21	3.98E-21	3.98E-21
Y(1)=0.000E+00	0.00E+00	4.86E-26	4.86E-26	4.86E-26	4.86E-26	4.86E-26	6.34E-23	1.80E-21	3.98E-21	3.98E-21
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF H2 ---------- H2 ----------

Y(10)=9.000E-03	5.42E-07	5.42E-07	7.43E-07	9.69E-07	8.73E-07	1.20E-12	7.77E-14	1.31E-14	8.15E-15	8.15E-15
Y(9)=8.000E-03	5.42E-07	5.42E-07	7.43E-07	9.69E-07	8.73E-07	1.20E-12	7.77E-14	1.31E-14	8.15E-15	8.15E-15
Y(8)=6.750E-03	5.51E-07	5.51E-07	7.53E-07	9.82E-07	8.80E-07	1.23E-12	9.04E-14	1.49E-14	7.96E-15	7.96E-15
Y(7)=4.750E-03	5.51E-07	5.51E-07	7.52E-07	9.81E-07	9.07E-07	1.31E-12	1.20E-13	1.68E-14	7.69E-15	7.69E-15
Y(6)=3.750E-03	5.43E-07	5.43E-07	7.42E-07	9.68E-07	9.05E-07	1.33E-12	1.28E-13	1.28E-14	6.13E-15	6.13E-15
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.80E-15	4.73E-15	4.73E-15
Y(4)=2.750E-03	0.00E+00	1.59E-20	1.59E-20	1.59E-20	1.59E-20	1.59E-20	5.34E-17	3.82E-15	3.51E-15	3.51E-15
Y(3)=1.500E-03	0.00E+00	1.59E-20	1.59E-20	1.59E-20	1.59E-20	1.59E-20	3.26E-17	1.15E-15	1.85E-15	1.85E-15
Y(2)=5.000E-04	0.00E+00	1.59E-20	1.59E-20	1.59E-20	1.59E-20	1.59E-20	2.08E-17	5.91E-16	1.31E-15	1.31E-15
Y(1)=0.000E+00	0.00E+00	1.59E-20	1.59E-20	1.59E-20	1.59E-20	1.59E-20	2.08E-17	5.91E-16	1.31E-15	1.31E-15
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF H2O ---------- H2O ----------

Y(10)=9.000E-03	8.36E-02	8.36E-02	8.36E-02	8.35E-02	8.01E-02	3.38E-03	2.19E-04	3.71E-05	2.30E-05	2.30E-05
Y(9)=8.000E-03	8.36E-02	8.36E-02	8.36E-02	8.35E-02	8.01E-02	3.38E-03	2.19E-04	3.71E-05	2.30E-05	2.30E-05
Y(8)=6.750E-03	8.36E-02	8.36E-02	8.36E-02	8.35E-02	8.02E-02	3.48E-03	2.55E-04	4.20E-05	2.25E-05	2.25E-05
Y(7)=4.750E-03	8.36E-02	8.36E-02	8.36E-02	8.35E-02	8.04E-02	3.70E-03	3.38E-04	4.75E-05	2.17E-05	2.17E-05
Y(6)=3.750E-03	8.36E-02	8.36E-02	8.36E-02	8.35E-02	8.04E-02	3.76E-03	3.61E-04	3.62E-05	1.73E-05	1.73E-05
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.20E-05	1.34E-05	1.34E-05
Y(4)=2.750E-03	0.00E+00	4.50E-11	4.50E-11	4.50E-11	4.50E-11	4.50E-11	1.51E-07	1.08E-05	9.91E-06	9.91E-06
Y(3)=1.500E-03	0.00E+00	4.50E-11	4.50E-11	4.50E-11	4.50E-11	4.50E-11	9.22E-08	3.26E-06	5.24E-06	5.24E-06
Y(2)=5.000E-04	0.00E+00	4.50E-11	4.50E-11	4.50E-11	4.50E-11	4.50E-11	5.87E-08	1.67E-06	3.69E-06	3.69E-06
Y(1)=0.000E+00	0.00E+00	4.50E-11	4.50E-11	4.50E-11	4.50E-11	4.50E-11	5.87E-08	1.67E-06	3.69E-06	3.69E-06
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF O ---------- O ----------

Y(10)=9.000E-03	1.27E-07	1.27E-07	2.23E-07	3.59E-07	3.08E-07	1.89E-16	1.23E-17	2.08E-18	1.29E-18	1.29E-18
Y(9)=8.000E-03	1.27E-07	1.27E-07	2.23E-07	3.59E-07	3.08E-07	1.89E-16	1.23E-17	2.08E-18	1.29E-18	1.29E-18
Y(8)=6.750E-03	1.30E-07	1.30E-07	2.29E-07	3.68E-07	3.18E-07	1.95E-16	1.43E-17	2.35E-18	1.26E-18	1.26E-18
Y(7)=4.750E-03	1.30E-07	1.30E-07	2.28E-07	3.68E-07	3.29E-07	2.00E-16	1.90E-17	2.66E-18	1.22E-18	1.22E-18
Y(6)=3.750E-03	1.27E-07	1.27E-07	2.23E-07	3.59E-07	3.28E-07	2.11E-16	2.03E-17	2.03E-18	9.72E-19	9.72E-19
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-18	7.50E-19	7.50E-19
Y(4)=2.750E-03	0.00E+00	2.52E-24	2.52E-24	2.52E-24	2.52E-24	2.52E-24	8.47E-21	6.06E-19	5.56E-19	5.56E-19
Y(3)=1.500E-03	0.00E+00	2.52E-24	2.52E-24	2.52E-24	2.52E-24	2.52E-24	5.17E-21	1.83E-19	2.94E-19	2.94E-19
Y(2)=5.000E-04	0.00E+00	2.52E-24	2.52E-24	2.52E-24	2.52E-24	2.52E-24	3.29E-21	9.36E-20	2.07E-19	2.07E-19
Y(1)=0.000E+00	0.00E+00	2.52E-24	2.52E-24	2.52E-24	2.52E-24	2.52E-24	3.29E-21	9.36E-20	2.07E-19	2.07E-19
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF OH ---------- OH ----------

Y(10)=9.000E-03	2.28E-05	2.28E-05	3.21E-05	4.29E-05	3.85E-05	2.55E-11	1.66E-12	2.80E-13	1.74E-13	1.74E-13
Y(9)=8.000E-03	2.28E-05	2.28E-05	3.21E-05	4.29E-05	3.85E-05	2.55E-11	1.66E-12	2.80E-13	1.74E-13	1.74E-13
Y(8)=6.750E-03	2.31E-05	2.31E-05	3.26E-05	4.36E-05	3.92E-05	2.62E-11	1.93E-12	3.17E-13	1.70E-13	1.70E-13
Y(7)=4.750E-03	2.31E-05	2.31E-05	3.26E-05	4.35E-05	4.01E-05	2.79E-11	2.55E-12	3.59E-13	1.64E-13	1.64E-13
Y(6)=3.750E-03	2.28E-05	2.28E-05	3.21E-05	4.29E-05	4.00E-05	2.84E-11	2.73E-12	2.73E-13	1.31E-13	1.31E-13
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.66E-13	1.01E-13	1.01E-13
Y(4)=2.750E-03	0.00E+00	3.40E-19	3.40E-19	3.40E-19	3.40E-19	3.40E-19	1.14E-15	8.15E-14	7.48E-14	7.48E-14
Y(3)=1.500E-03	0.00E+00	3.40E-19	3.40E-19	3.40E-19	3.40E-19	3.40E-19	6.96E-16	2.46E-14	3.96E-14	3.96E-14
Y(2)=5.000E-04	0.00E+00	3.40E-19	3.40E-19	3.40E-19	3.40E-19	3.40E-19	4.43E-16	1.26E-14	2.79E-14	2.79E-14
Y(1)=0.000E+00	0.00E+00	3.40E-19	3.40E-19	3.40E-19	3.40E-19	3.40E-19	4.43E-16	1.26E-14	2.79E-14	2.79E-14
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF PR ---------- PR ----------

Y(10)=9.000E-03	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.78E-01	7.50E-03	4.87E-04	8.25E-05	5.11E-05	5.11E-05
Y(9)=8.000E-03	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.78E-01	7.50E-03	4.87E-04	8.25E-05	5.11E-05	5.11E-05
Y(8)=6.750E-03	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.78E-01	7.72E-03	5.67E-04	9.33E-05	5.00E-05	5.00E-05
Y(7)=4.750E-03	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.79E-01	8.22E-03	7.52E-04	1.06E-04	4.82E-05	4.82E-05
Y(6)=3.750E-03	1.86E-01	1.86E-01	1.86E-01	1.86E-01	1.79E-01	8.34E-03	8.03E-04	8.04E-05	3.85E-05	3.85E-05
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.89E-05	2.97E-05	2.97E-05
Y(4)=2.750E-03	0.00E+00	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	3.35E-07	2.40E-05	2.20E-05	2.20E-05
Y(3)=1.500E-03	0.00E+00	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	2.05E-07	7.25E-06	1.16E-05	1.16E-05
Y(2)=5.000E-04	0.00E+00	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.30E-07	3.71E-06	8.20E-06	8.20E-06
Y(1)=0.000E+00	0.00E+00	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.00E-10	1.30E-07	3.71E-06	8.20E-06	8.20E-06
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF TEM ---------- TEM ----------

Y(10)=9.000E-03	6.38E+02	6.38E+02	7.39E+02	7.63E+02	6.86E+02	6.45E+02	6.29E+02	6.23E+02	6.20E+02	6.19E+02
Y(9)=8.000E-03	1.68E+03	1.48E+03	1.73E+03	1.77E+03	1.76E+03	4.22E+02	3.53E+02	3.47E+02	3.45E+02	6.18E+02
Y(8)=6.750E-03	1.68E+03	1 E+03	1.73E+03	1.78E+03	1.77E+03.	4.23E+02	3.53E+02	3.46E+02	3.44E+02	6.18E+02
Y(7)=4.750E-03	1.68E+03	1.68E+03	1.73E+03	1.78E+03	1.77E+03	4.27E+02	3.55E+02	3.45E+02	3.43E+02	6.18E+02
Y(6)=3.750E-03	1.68E+03	1.68E+03	1.73E+03	1.77E+03	1.77E+03	4.28E+02	3.55E+02	3.44E+02	3.42E+02	6.18E+02
Y(5)=3.250E-03	4.89E+02	4.89E+02	5.11E+02	5.28E+02	4.54E+02	4.12E+02	4.04E+02	3.43E+02	3.42E+02	6.18E+02
Y(4)=2.750E-03	2.75E+02	2.97E+02	3.15E+02	3.33E+02	3.40E+02	3.41E+02	3.42E+02	3.42E+02	3.42E+02	6.18E+02
Y(3)=1.500E-03	2.75E+02	2.93E+02	3.10E+02	3.28E+02	3.36E+02	3.39E+02	3.40E+02	3.40E+02	3.41E+02	6.17E+02
Y(2)=5.000E-04	2.75E+02	2.92E+02	3.08E+02	3.26E+02	3.35E+02	3.38E+02	3.39E+02	3.40E+02	3.40E+02	6.17E+02
Y(1)=0.000E+00	2.75E+02	2.92E+02	3.08E+02	3.26E+02	3.35E+02	3.38E+02	3.39E+02	3.40E+02	3.40E+02	6.17E+02
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF P ---------- P ----------

Y(9)=8.000E-03	-8.16E+01	-7.80E+01	-7.52E+01	-6.63E+01	-6.61E+01	-6.65E+01	-6.67E+01	-5.68E+01
Y(8)=6.750E-03	-8.16E+01	-7.80E+01	-7.52E+01	-6.63E+01	-6.60E+01	-6.63E+01	-6.87E+01	-5.82E+01
Y(7)=4.750E-03	-8.16E+01	-7.80E+01	-7.52E+01	-6.63E+01	-6.60E+01	-6.64E+01	-6.95E+01	-5.78E+01
Y(6)=3.750E-03	-8.16E+01	-7.80E+01	-7.52E+01	-6.63E+01	-6.60E+01	-6.63E+01	-6.99E+01	-5.60E+01
Y(5)=3.250E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-7.05E+01	-5.46E+01
Y(4)=2.750E-03	2.35E-01	-1.99E+01	-3.76E+01	-5.62E+01	-6.32E+01	-6.65E+01	-6.88E+01	-5.29E+01
Y(3)=1.500E-03	2.37E-01	-1.99E+01	-3.76E+01	-5.62E+01	-6.32E+01	-6.65E+01	-6.82E+01	-5.10E+01
Y(2)=5.000E-04	0.00E+00	-1.99E+01	-3.76E+01	-5.62E+01	-6.32E+01	-6.65E+01	-6.79E+01	-5.08E+01
X(IX)	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207

FIELD VALUES OF RHO ---------- RHO ----------

Y(10)=9.000E-03	4.01E-01	4.01E-01	3.90E-01	3.81E-01	3.83E-01	1.60E+00	1.91E+00	1.94E+00	1.95E+00	2.54E+00
Y(9)=8.000E-03	4.01E-01	4.01E-01	3.90E-01	3.81E-01	3.83E-01	1.60E+00	1.91E+00	1.94E+00	1.95E+00	2.54E+00
Y(8)=6.750E-03	4.00E-01	4.00E-01	3.89E-01	3.80E-01	3.82E-01	1.59E+00	1.91E+00	1.95E+00	1.96E+00	2.54E+00
Y(7)=4.750E-03	4.00E-01	4.00E-01	3.89E-01	3.80E-01	3.81E-01	1.58E+00	1.90E+00	1.95E+00	1.96E+00	2.54E+00
Y(6)=3.750E-03	4.01E-01	4.01E-01	3.90E-01	3.81E-01	3.82E-01	1.57E+00	1.90E+00	1.96E+00	1.97E+00	2.54E+00
Y(5)=3.250E-03	2.45E+00	2.45E+00	2.45E+00	2.45E+00	2.45E+00	2.45E+00	2.45E+00	1.97E+00	1.97E+00	2.54E+00
Y(4)=2.750E-03	2.52E+00	2.28E+00	2.14E+00	2.02E+00	1.98E+00	1.97E+00	1.97E+00	1.97E+00	1.97E+00	2.54E+00
Y(3)=1.500E-03	2.52E+00	2.30E+00	2.17E+00	2.05E+00	2.00E+00	1.99E+00	1.98E+00	1.98E+00	1.98E+00	2.54E+00
Y(2)=5.000E-04	1.40E+00	2.26E+00	2.18E+00	2.06E+00	2.01E+00	1.99E+00	1.99E+00	1.98E+00	1.98E+00	2.54E+00
Y(1)=0.000E+00	1.40E+00	2.26E+00	2.18E+00	2.06E+00	2.01E+00	1.99E+00	1.99E+00	1.98E+00	1.98E+00	2.54E+00
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

FIELD VALUES OF EMU ---------- EMU ----------

Y(10)=9.000E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(9)=8.000E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(8)=6.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(7)=4.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(6)=3.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(5)=3.250E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(4)=2.750E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(3)=1.500E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(2)=5.000E-04	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
Y(1)=0.000E+00	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03	1.19E-03
X(IX)	1= 0.000	2= 0.030	3= 0.070	4= 0.120	5= 0.170	6= 0.188	7= 0.197	8= 0.202	9= 0.207	10= 0.210

APPENDIX E

UPDATE TO COMPUTE THE STANTON NUMBERS

E.1 Introduction

Appendix E is concerned with the calculation of the Stanton numbers. The basic theoretical background may be found in detail in Ref. 7. Therefore only a brief account is given here.

E.2 Theory

When the shear stress is uniform through a Couette-flow layer (which implies negligible pressure gradient and mass transfer), when the fluid properties (apart from turbulence effects on transport) are uniform, when the wall is smooth, and when the Reynolds number R is sufficiently high (>11.5)*, the following relations result from integrating the equations:

$$s = \left[\kappa/\ell n\ (ER s^{\frac{1}{2}})\right]^2 \qquad \text{(E-1)}$$

$$S = s/\left[\sigma_t\ (1+s^{\frac{1}{2}}P)\right] \qquad \text{(E-2)}$$

$$H = \sigma_t \qquad \text{(E-3)}$$

where: s is the shear-stress coefficient ($=\tau/\rho u^2$).
S is the Stanton number.
H is the recovery factor.
E is the constant in the log. wall-shear-stress expression.
R is the Reynolds number ($=\rho uy/_{\mu}$).
and P is an integration constant.

* This value is derived by equating the laminar and turbulent expressions for shear stress and solving for y+ (the well-known non-dimensional distance) I.E. it represents the point where the two shear stress curves intersect.

E can be taken as 9.0 (see Ref. 7), while P is a function of the laminar Prandtl-Schmidt number σ and its supposed turbulent counterpart, σ_t; the latter function is fitted quite well by the relation:

$$9.0(\sigma/\sigma_t - 1)\ (\sigma_t/\sigma)^{\frac{1}{4}} \qquad \text{(E-4)}$$

(see Ref. 13).

These relations are known to fit experimental data quite well in situations for which the assumptions apply, e.g. fully-developed turbulent pipe flows, and turbulent boundary layers on flat plates. Equation (E-4) should not be used for σ values below 0.5.

E.3 Computational details

The only routines requiring modification for the six Stanton numbers* calculation are SOURCE and WALL.

The first business of WALL is to calculate indices, properly locating the wall under consideration. Thereafter, if laminar flow is indicated by R being less than 132.25 ($\equiv 11.5^2$), the laminar-flow velocity sequence is sought at statement number 19 for velocity and at statement number 410 for enthalpy. It will not be hard for the reader to recognise, in these two program passages, the FORTRAN equivalents of the formulae which are given above.

Because of the fact that equation (E-1) contains s on both sides, iterative solution is needed; this is the reason for the DO.17 loop which is left if the number of iterations (NIT) equals 11 or $s^{\frac{1}{2}}$ differs by less than 0.0001 from its previous value. Then the Stanton number is calculated

* I.E. Stanton numbers at inner surface of end wall, at outer surface of end wall, at outer surface of inner tube, at inner surface of inner tube, at inner surface of outer tube and at outer surface of outer tube.

according to equation (E-2), and is printed out for KTEST>0. The only modifications to the subroutine SOURCE are inserted in Chapter 4, i.e. in the Chapter where the source terms for $\tilde{h}$ are computed. The modifications consist of calling subroutine WALL to calculate the Stanton numbers prior to their use for the calculation of heat transfer.

E.4 Additional FORTRAN Symbols

NAME	LOCATION	TYPE	MEANING
PJAY	WALL		Jayatillaka's P function
PRRAT	WALL		Prandtl number ratio
STERM	WALL		Stanton number

E.5 Listing of modified subroutines

The listing of the two modified subroutines SOURCE and WALL follows.

```
ELU   1,2,3,3
      SUBROUTINE WALL(I1,STERM,STERM1,IY,JPHI)
      COMMON/COMA/ U(480),V(475),H(500),FM(500),FUE(500),FS(500,15),      WA000030
     1 PP(20),TEM(500),P(414),RHO(500),EMU(500),                          WA000040
     1 DXG(25),DXU(25),KOUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),     WA000050
     2 STORE(25),SXG(25),SXU(25),X(25),XU(25),                            WA000060
     3 A(20),AE(20),AN(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),       WA000070
     4 BSNIP(20),C(20),CSNIP(20),DIFE(20),DIFEE(20),DIFN(20),             WA000080
     5 DIFNE(20),DIFW(20),DSNIP(20),DU(20),DV(20),DYG(20),DYV(20),        WA000090
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),         WA000100
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),      WA000110
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AEDDX(500),             WA000120
     9 ANDDY(500),AREAN(500),VOL(500),                                    WA000130
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),               WA000140
     1 IEW(25),ILAST(25),IMON(25),IXNY(25),IZERO(25),KSOLVE(25),          WA000150
     2 RSREF(25),RSSUM(25),TITLE(25)                                      WA000160
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)        WA000170
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),            WA000180
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))                 WA000190
      COMMON/COMB/                                                        WA000200
     1 AK,ARRCON,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,       WA000210
     2 EPST,EQRAT,EWALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,            WA000220
     3 FSTOIM,FUB,FUC,HFU,HW,INC,INERT,IPLRS,IPREF,IPRINT,ISNIP,          WA000230
     4 ISWEEP,IX,IXMON,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,            WA000240
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,       WA000250
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,         WA000260
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPRI,KLT,KRAD,KRHOMU,KSWEEP,KTEST,       WA000270
     8 LABPHI,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,       WA000280
     9 NXM2,NXYG,NXYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,         WA000290
     X PREEXP,PRESS,RELAXP,RF,RFSTM,RSCHEK,RSMAX,R1I,R1O,R2I,R2O,         WA000300
     1 STOICH,TB,TC,TINY,TMAX,TMIN,UB,UC,WMIX                             WA000310
      COMMON/HTR/ ALNR1I,ALNR1O,ALNR2I,ALNR2O,COND,EL3,
     1 EMIS1O,EMIS2I,EMIS2O,EMISX1,EMISXO,REMI,RHOINF,
     1 SIGMA,STXI,STXO,ST1I,ST1O,ST2I,ST2O,TINF,UINF,VINF,WAREA
      DATA SHALF/0.04/                                                    WA000320
      KWALL=2-1/I1                                                        WA000330
      I2=I1+3-2*KWALL                                                     WA000340
      I3=I1+2-KWALL                                                       WA000350
      IF (IY.NE.0) GO TO 10000                                            WA000360
      I=I2+IX1NY                                                          WA000370
      IF (JPHI.EQ.JU)   GO TO 10                                          WA000380
      IF(JPHI.EQ.JH) GO TO 400
      RETURN                                                              WA000390
C                                                                         WA000400
   10 I=I2+IX1NYU                                                         WA000410
      RUREF=RHO(I)*ABS(U(1))                                              WA000420
      RE=RUREF*DYG(I3)/EMUREF                                             WA000430
      IF(KLT.EQ.1) GO TO 19                                               WA000440
      IF (RE.LT.132.25) GO TO 19                                          WA000450
      ER=RE*EWALL                                                         WA000460
      ARGMIN=11.5*EWALL                                                   WA000470
      DO 17 NIT=1,11                                                      WA000480
      SHALF1=SHALF                                                        WA000490
      ARG=ER*SHALF                                                        WA000500
      IF (ARG.LT.ARGMIN) GO TO 19                                         WA000510
      SHALF=AK/ALOG(ARG)                                                  WA000520
      IF (ABS(SHALF-SHALF1).LT.0.0001) GO TO 18                           WA000530
   17 CONTINUE                                                            WA000540
   18 S=SHALF**2                                                          WA000550
      STERM1=S*R(I2)*RUREF*SXU(IXU)                                       WA000560
      RETURN                                                              WA000570
   19 STERM1=EMUREF*SXU(IXU)*R(I1)*RDYG(I3)                               WA000580
```

```
      RETURN                                                            WA000590
  400 CONTINUE
      I=I1+IX1NY
      IW=I-NY
      YREF=DYG(NY)
      IF(I1.EQ.IYWM1)  YREF=0.5*DYG(IYW)
      IF(I1.EQ.IYWP1)  YREF=0.5*DYG(IYWP1)
      RUREF=RHO(I)*0.5*ABS(U(I)+U(IW))
      IF(I1.EQ.NY) RUREF=RHOINF*UINF
      RE=RUREF*YREF/EMUREF
      IF(KLT.EQ.1)  GO TO 410
      IF(RE.LT.132.25) GO TO 410
      ER=RE*EWALL
      ARGMIN=11.5*EWALL
      NIT=0
  401 SHALF1=SHALF
      ARG=ER*SHALF
      IF(ARG.LT.ARGMIN) GO TO 410
      SHALF=AK/ALOG(ARG)
      IF(ABS(SHALF-SHALF1).LT.0.0001) GO TO 402
      NIT=NIT+1
      IF(NIT.LT.11) GO TO 401
  402 S=SHALF**2
      PRRAT=PRL(JPHI)/PRT(JPHI)
      PJAY=9.0*(PRRAT-1.0)/PRRAT**0.25
      STERM=S/(PRT(JPHI)*(1.0+AMAX1(-0.9999,PJAY*SHALF)))
      GO TO 411
  410 STERM=1.0/(PRL(JPHI)*RE)
  411 CONTINUE
      IF(KTEST.GT.0) WRITE(6,412) I1,IY,STERM,NTRAV
  412 FORMAT(10(1H*),2I3,E20.8,I3)
      RETURN
10000 I=IY+IX1NY                                                        WA000600
      IV=IY+IX1NY1
      IVS=IV-1
      IF (JPHI.EQ.JV)   GO TO 200                                       WA000610
      IF(JPHI.EQ.JH) GO  TO   4000
      RETURN                                                            WA000620
  200 RUREF=RHO(I)*ABS(V(IV))                                           WA000630
      RE=RUREF*DXG(I3)/EMUREF                                           WA000640
      IF(KLT.EQ.1) GO TO 290                                            WA000650
      IF (RE.LT.132.25) GO TO 290                                       WA000660
      ER=RE*EWALL                                                       WA000670
      ARGMIN=11.5*EWALL                                                 WA000680
      DO 270 NIT=1,11                                                   WA000690
      SHALF1=SHALF                                                      WA000700
      ARG=ER*SHALF                                                      WA000710
      IF (ARG.LT.ARGMIN) GO TO 290                                      WA000720
      SHALF=AK/ALOG(ARG)                                                WA000730
      IF (ABS(SHALF-SHALF1).LT.0.0001) GO TO 280                        WA000740
  270 CONTINUE                                                          WA000750
  280 S=SHALF**2                                                        WA000760
      STERM1=S*RUREF*SYV(IY)*RV(IY)                                     WA000770
      RETURN                                                            WA000780
  290 STERM1=EMUREF*SYV(IY)*RV(IY)*RDXG(I3)                             WA000790
      RETURN                                                            WA000800
```

```
4000 CONTINUE
     YREF=DXG(NX)
     RUREF=RHO(I)*0.5*ABS(V(IV)+V(IVS))
     IF(I1.EQ.NX.OR.IX.EQ.NX) RUREF=RHOINF*VINF
     RE=RUREF*YREF/EMUREF
     IF(KLT.EQ.1) GO TO 4100
     IF(RE.LT.132.25) GO TO 4100
     ER=RE*EWALL
     ARGMIN=11.5*EWALL
     NIT=0
4010 SHALF1=SHALF
     ARG=ER*SHALF
     IF(ARG.LT.ARGMIN) GO  TO  4100
     SHALF=AK/ALOG(ARG)
     IF(ABS(SHALF-SHALF1).LT.0.0001)  GO  TO 4020
     NIT=NIT+1
     IF(NIT.LT.11)  GO TO  4010
4020 S=SHALF**2
     PRRAT=PRL(JPHI)/PRT(JPHI)
     PJAY=9.0*(PRRAT-1.0)/PRRAT**0.25
     STERM=S/(PRT(JPHI)*(1.0+AMAX1(-0.9999,PJAY*SHALF)))
     GO TO  4110
4100 STERM=1.0/(PRL(JPHI)*RE)
4110 CONTINUE
     IF(KTEST.GT.0) WRITE(6,412) I1,IY,STERM,NTRAV
     RETURN
     END                                                          WA000810
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
ELO   1,2,3,3
      SUBROUTINE SOURCE(LPH1)
C-------------------------------------------------------------------S0000030
CHAPTER  0  0  0  0  0  0  0  0     DECLARATIONS  0  0  0  0  0  0  0  S0000040
C-------------------------------------------------------------------S0000050
      COMMON/COMA/ U(480),V(475),H(500),PM(500),PUE(500),PS(500,15),   S0000060
     1 PP(20),TEM(500),P(414),RHO(500),EMU(500),                       S0000070
     1 RXG(25),RXU(25),ROUNT(25),RDXG(25),RDXU(25),RSXG(25),RSXU(25),  S0000080
     2 SIGMA(25),SXG(25),SXU(25),X(25),XU(25),                         S0000090
     3 A(20),AE(20),AW(20),AREAE(20),AS(20),ASNIP(20),AW(20),B(20),    S0000100
     4 BSQIP(20),C(20),CSQIP(20),DIFE(20),DIFEE(20),DIFN(20),          S0000110
     5 DIFNE(20),DIFW(20),DSQIP(20),DU(20),DV(20),DYG(20),DYV(20),     S0000120
     6 FLOWE(20),FLOWEE(20),FLOWN(20),FLOWNE(20),FLOWW(20),R(20),      S0000130
     7 RDYG(20),RDYV(20),RSYG(20),RSYV(20),RV(20),RVCB(20),RVSQ(20),   S0000140
     8 SP(20),SU(20),SYG(20),SYV(20),Y(20),YV(20),AECOX(500),          S0000150
     9 AMODY(500),AREAN(500),VOL(500),                                 S0000160
     X ARSL(25,25),PREFF(25),PRL(25),PRT(25),RSLINE(25,25),            S0000170
     1 IEW(25),ILAST(25),IMON(25),IXMY(25),IZERO(25),KSOLVE(25),       S0000180
     2 RSREF(25),RSSUM(25),TITLE(25)                                   S0000190
      DIMENSION DIFNW(20),DIFWW(20),F(11889),FLOWNW(20),FLOWWW(20)     S0000200
      EQUIVALENCE(F(1),U(1)),(FLOWNW(1),FLOWNE(1)),(FLOWWW(1),         S0000210
     1 FLOWEE(1)),(DIFNW(1),DIFNE(1)),(DIFWW(1),DIFEE(1))              S0000220
      COMMON/COMB/                                                     S0000230
     1 AK,ARRCON,BIG,CCHECK,CMIX,DATA(6),DP,EL1,EL2,EMA,EMF,EMUREF,    S0000240
     2 EPSI,EGRAT,EGRALL,FLOB,FLOC,FLOWIN,FLOWST,FLOWUP,FSTOIC,        S0000250
     3 FSTOIM,FUB,FUC,HFU,HW,IDC,INERT,IPLRS,IPREF,IPRINT,ISWIP,       S0000260
     4 ISWEEP,IX,IXMOM,IXPREF,IXP1,IXU,IXUP1,IXW,IX1NY,IX1NYU,         S0000270
     5 IX1NY1,IX2NYU,IX2NY2,IYF,IYFM1,IYFUEL,IYL,IYLM1,IYLP1,IYMON,    S0000280
     6 IYPREF,IYW,IYWM1,IYWP1,JEMU,JFM,JFUE,JH,JLAST,JP,JPP,JRHO,      S0000290
     7 JS1,JS2,JTEM,JU,JV,KASE,KINPR1,KLT,KRAD,KRHOMU,KSWEEP,KTEST,    S0000300
     8 LABPH1,LSWEEP,NSOLVE,NTDMA,NTMAX,NTRAV,NUMCOL,NX,NXMAX,NXM1,    S0000310
     9 NXM2,NAYG,NAYP,NXYU,NXYV,NY,NYMAX,NYM1,NYM2,OXB,OXC,PJAY,       S0000320
     X PREXP,PRESS,RELAXP,RF,RFSTM,RSCHEK,RSMAX,R11,R10,R21,R20,       S0000330
     1 STOICH,TS,TC,TINY,TMAX,TMIN,UB,UC,WMIX                          S0000340
      LOGICAL CONVG                                                    S0000350
      COMMON /INDEX/ IDCO,IDCO2,IDF,IDH,IDH2,IDH20,IDO,IDOH,IDO2,IDN,  S0000360
     1 IDMC,IDMO2,IDN2,IDN20,IEQUIL,IHCPS,IPR,JJ,KNTCS,NA,NLM,         S0000370
     2 NS,NSE1,NSE2,NSK,NSM,NS1,NS2,ID(4,15)                           S0000380
     3/PARAMS/ CONVG,ENV,EPSS,GASCON,IDEBUG,ITMAX,PA,SM,TINYK,TK,TLIM,TNYS0000390
     5/SPECIES/ASUB(20,3),CPSUM,HSUM,HO(14),SNM(14),SO(14),S1(14),     S0000400
     6 S2(14),Z(2,7,14)                                                S0000410
     7/CEQUIL/AC1,AC2,AC3,AC4,AH1,AH2,AH3,AH4,ASM1,ASM2,ASM3,ASM4,     S0000420
     8 AS1(4,7,2),HDIV,HMAX,HMIN,PEXP(7)                               S0000430
     9/REACTS/BX(15),FX2(15),TACT(15),TACT2(15),TEN(15),TEN2(15)       S0000440
      COMMON/DTR/ ALNR11,ALNR10,ALNR21,ALNR20,COND,EL3,                S0000450
     1 EMISIO,EMISZI,EMISZO,EMISX1,EMISXO,REMI,RHOINF,                 S0000460
     1 SIGMA,STX1,STXO,ST11,ST10,ST21,ST20,TINF,UINF,VINF,WAREA        S0000470
C-------------------------------------------------------------------S0000480
CHAPTER 1  1  1  1  1  1  1    PRELIMINARIES  1  1  1  1  1  1  1  1  S0000490
C-------------------------------------------------------------------S0000500
      DATA SHALF/0.04/                                                 S0000510
      JPH1=LPH1                                                        S0000520
```

```
      IF(JPH1.EQ.JU)   GO TO 10                                          S0000530
      IF(JPH1.EQ.JV)   GO TO 20                                          S0000540
      IF(JPH1.EQ.JH)   GO TO 40                                          S0000550
      IF(JPH1.EQ.JPM)  GO TO 50                                          S0000560
      IF(JPH1.EQ.JFUE) GO TO 60                                          S0000570
      IF(JPH1.EQ.JPP)  GO TO 90                                          S0000580
      RETURN                                                             S0000590
C-----------------------------------------------------------------------S0000600
CHAPTER 2 2 2 2 2 2  SOURCE TERMS FOR U  2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 S0000610
C-----------------------------------------------------------------------S0000620
   10 ICONST=IX2NYU-1                                                    S0000630
      IF (KRHOMU.EQ.0) GO TO 12                                          S0000640
      RDXU1X=RDXU(IXU)                                                   S0000650
      RDXU11=RDXU(IXUP1)                                                 S0000660
      RSXU1X=RSXU(IXU)                                                   S0000670
      GRDXS=0.25*RDXG(IXUP1)                                             S0000680
C                                                                        S0000690
      I=IYFM1+IX1NYU                                                     S0000700
      IL=I+NY                                                            S0000710
      IN=I+1                                                             S0000720
      INL=IN+NY                                                          S0000730
      IXU1NY=(IXU-1)*NY+1                                                S0000740
      IV=IYFM1+IXU1NY                                                    S0000750
      IEV=IV+NY+1                                                        S0000760
      EDVDXN=(EMU(I)+EMU(IE)+EMU(IN)+EMU(INE))*(V(IEV)-V(IV))*RV(IYFM1)  S0000770
      DO 11 IY=IYF,IYL                                                   S0000780
      I=IY+IX1NYU                                                        S0000790
      IE=I+NY                                                            S0000800
      IW=I-NY                                                            S0000810
      IN=I+1                                                             S0000820
      INL=IN+NY                                                          S0000830
      IV=IY+IXU1NY                                                       S0000840
      IEV=IV+NY+1                                                        S0000850
      IP=IY+ICONST                                                       S0000860
      IEP=IP+NY+2                                                        S0000870
      DUDXW=(U(I)-U(IW))*RDXU1X                                          S0000880
      DUDXE=(U(IE)-U(I))*RDXU11                                          S0000890
      STERM=(EMU(IE)*DUDXE-EMU(IW)*DUDXW)*RSXU1X                         S0000900
      EDVDXS=EDVDXN                                                      S0000910
      EDVDXN=(EMU(I)+EMU(IE)+EMU(IN)+EMU(INE))*(V(IEV)-V(IV))*RV(IY)     S0000920
      STERM=STERM+(EDVDXN-EDVDXS)*GRDXG/AREAE(IY)                        S0000930
      SU(IY)=AREAE(IY)*(P(IP)-P(IEP))+0.5*STERM*(VOL(I)+VOL(IE))         S0000940
      SP(IY)=0.0                                                         S0000950
C---------- INERTIAL UNDER-RELAXATION ----------------------------------S0000960
      AFAC=0.0                                                           S0000970
      ASU=AFAC*ABS(SU(IY))                                               S0000980
      AFACT=ASU/(ABS(U(I))+1NY)                                          S0000990
      AFAT=1.0E3*ASU                                                     S0001000
      AFACT=AMIN1(AFACT,AFAT)                                            S0001010
      SU(IY)=SU(IY)+AFACT*U(I)                                           S0001020
      SP(IY)=SP(IY)-AFACT                                                S0001030
   11 CONTINUE                                                           S0001040
```

```
      GO TO 14                                                          S0001050
   12 DO 13 IY=IYF,IYL                                                  S0001060
      IP=IY+ICONST                                                      S0001070
      IEP=IP+NY+2                                                       S0001080
      SC(IY)=AREAL(IY)*(P(IP)-P(IEP))                                   S0001090
   13 SP(IY)=0.0                                                        S0001100
C                                                                       S0001110
   14 IF(IXO.EQ.IXW.AND.INC.EQ.-1) GO TO 1000                           S0001120
      GO TO 1002                                                        S0001130
 1000 DO 1001 IY=2,IYY                                                  S0001140
      I=IY+IX1NYO                                                       S0001150
      SC(IY)=SIG*O(I)                                                   S0001160
 1001 SP(IY)=-SIG                                                       S0001170
C-----EXTRA SOURCES DUE TO INNER TUBE.                                  S0001180
 1002 IF (IXO.GT.IXW) RETURN                                            S0001190
      IF (INC.NE.1) GO TO 15                                            S0001200
      I2=IY+M1                                                          S0001210
      I3=IY                                                             S0001220
      GO TO 16                                                          S0001230
   15 I2=IY+P1                                                          S0001240
      I3=IY+P1                                                          S0001250
   16 I=I2+IX1*NYO                                                      S0001260
      RHOREF=RHO(I)*ABS(O(I))                                           S0001270
      RE=0.5*RHOREF*DYG(I3)/EMUREF                                      S0001280
      IF(KLT.EQ.1) GO TO 19                                             S0001290
      IF (RE.LT.192.25) GO TO 19                                        S0001300
      ER=RE*EWALL                                                       S0001310
      ARGMIN=11.5*EWALL                                                 S0001320
      DO 17 NIT=1,11                                                    S0001330
      SHALF1=SHALF                                                      S0001340
      ARG=ER*SHALF                                                      S0001350
      IF (ARG.LT.ARGMIN) GO TO 19                                       S0001360
      SHALF=AR/ALOG(ARG)                                                S0001370
      IF(ABS(SHALF-SHALF1).LT.0.0001) GO TO 18
   17 CONTINUE
   18 S=SHALF**2                                                        S0001400
      SP(I2)=SP(I2)-S*R(I2)*RHOREF*SXO(IXO)                             S0001410
      RETURN                                                            S0001420
   19 SP(I2)=SP(I2)-EMUREF*SXO(IXO)*R(I2)/(DYG(I3)*0.5)                 S0001430
      RETURN                                                            S0001440
C-----------------------------------------------------------------------S0001450
CHAPTER 3  3  3  3  3  3   SOURCE TERMS FOR V   3  3  3  3  3  3  3  3  S0001460
C-----------------------------------------------------------------------S0001470
   20 ICONST=IX2*NY2-1                                                  S0001480
      IF(IX.EQ.2.AND.INC.EQ.-1) GO TO 25                                S0001490
      IF (XRHOMU.EQ.0) GO TO 22                                         S0001500
      RSXG=0.25*RSXG(IX)                                                S0001510
      IF=IYF+IX1NY                                                      S0001520
      IV=IYF-M1+IX1DY1                                                  S0001530
      EDVDY=EMU(IV)*(V(IV+1)-V(IV))*RDYV(IYF)*R(IYF)                    S0001540
      DO 21 IY=IYF,IYL-1                                                S0001550
      IYP1=IY+1                                                         S0001560
```

```
      I=IY+IX1IMY                                                          S0001570
      IN=I+1                                                               S0001580
      IE=I+IMY                                                             S0001590
      INE=IE+1                                                             S0001600
      IW=I-IMY                                                             S0001610
      INW=IW+1                                                             S0001620
      IV=IY+IX1IMY1                                                        S0001630
      IP=IY+ICOMST                                                         S0001640
      EMUM=EMU(I)+EMU(IN)                                                  S0001650
      EMUE=EMU(IE)+EMU(INE)                                                S0001660
      EMUW=EMU(IW)+EMU(INW)                                                S0001670
      STLR=(EMUE*(U(IN)-U(I))-EMUW*(U(INW)-U(IW)))*GRSXG*RDYG(IYP1)        S0001680
      EDVDYS=EDVDYN                                                        S0001690
      EDVDYN=EMU(IV)*(V(IV+1)-V(IV))*RDYV(IYP1)*R(IYP1)                    S0001700
      STLR=STLR+(EDVDYN-EDVDYS)/AREAE(IY)                                  S0001710
      VOLU=0.5*(VOL(I)+VOL(IN))                                            S0001720
      SU(IY)=STLR*VOLUME+AREAN(I)*(P(IP)-P(IP+1))                          S0001730
      SP(IY)=-EMUM*VOLUME/RVSM(IY)                                         S0001740
C------------ INERTIAL UNDER-RELAXATION ------------------------------     S0001750
      AFAC=0.0                                                             S0001760
      ASU=AFAC*ABS(SU(IY))                                                 S0001770
      AFACT=ASU/(ABS(V(IV))+1.0E-5)                                        S0001780
      AFAT=1.0E3*ASU                                                       S0001790
      AFACT=AMIN1(AFACT,AFAT)                                              S0001800
      SU(IY)=SU(IY)+AFACT*V(IV)                                            S0001810
      SP(IY)=SP(IY)-AFACT                                                  S0001820
   21 CONTINUE                                                             S0001830
      RETURN                                                               S0001840
   22 DO 23 IY=IYF,IYLM1                                                   S0001850
      I=IY+IX1IMY                                                          S0001860
      IN=I+1                                                               S0001870
      IP=IY+ICOMST                                                         S0001880
      SU(IY)=AREAN(I)*(P(IP)-P(IP+1))                                      S0001890
   23 SP(IY)=-.25*(EMU(I)+EMU(IN))*(VOL(I)+VOL(IN))/RVSM(IY)               S0001900
      RETURN                                                               S0001910
   25 DO 26 IY=IYF,IYLM1                                                   S0001920
      SU(IY)=0.0                                                           S0001930
   26 SP(IY)=-BIG                                                          S0001940
      RETURN                                                               S0001950
C-------------------------------------------------------------------------S0001960
CHAPTER 4  4  4  4  4  4   SOURCE TERMS FOR H  4  4  4  4  4  4  4  4     S0001970
C-------------------------------------------------------------------------S0001980
   40 CONTINUE                                                             S0001990
      DO 400 IY=IYF,IYL                                                    S0002000
      SU(IY)=0.0                                                           S0002010
  400 SP(IY)=0.0                                                           S0002020
C                                                                          S0002030
      IF(IX.EQ.NX) GO TO 450                                               S0002040
      I=IY+IX1IMY                                                          S0002050
      IS=I-1                                                               S0002060
      IN=I+1                                                               S0002070
      IE=I+IMY                                                             S0002080
```

```
      IW=I-NY                                                                  S0002090
      IWS=IW-1                                                                 S0002100
      IWW=IW+1                                                                 S0002110
      IWALL=(I+1)*NY                                                           S0002120
      IWALS=IWALL-1                                                            S0002130
      IWALE=IWALL+NY                                                           S0002140
      IWALW=IWALL-NY                                                           S0002150
      IWALSW=IWALW-1                                                           S0002160
C                                                                              S0002170
      GRADI3=0.0                                                               S0002180
      GRADI4=0.0                                                               S0002190
      IF(IX.GT.IXW) GO TO 415                                                  S0002200
      AE(IYW)=0.0                                                              S0002210
      AW(IYW)=0.0                                                              S0002220
      AS(IYW)=0.0                                                              S0002230
      AW(IYW)=0.0                                                              S0002240
      AS(IYWP1)=0.0                                                            S0002250
      AW(IYWP1)=0.0                                                            S0002260
      CALL GALL(IYWP1,STERM,STERM1,0,JH)
      ST11=STERM                                                               S0002270
      H11=ST11*RHO(IS)*ABS(0.5*(U(IS)+U(ISW)))*CMIX                            S0002280
      RU11=SXG(IX)/(1.0/(R11*H11)+ALUR11/CONU)                                 S0002290
      U11=RU11*TEM(IS)
      CALL GALL(IYWP1,STERM,STERM1,0,JH)
      ST10=STERM                                                               S0002300
      H10=ST10*RHO(IW)*ABS(0.5*(U(IW)+U(IWW)))*CMIX                            S0002310
      RU10=SXG(IX)/(1.0/(R10*H10)+ALUR10/CONU)                                 S0002320
      U10=RU10*TEM(IW)                                                         S0002330
      IF(IX.EQ.2) GO TO 401                                                    S0002340
      IF(IX.EQ.IXW) GO TO 405                                                  S0002350
      CAREA=CONE*AREAE(IYW)                                                    S0002360
      GAMAE=CAREA*RDXG(IXP1)                                                   S0002370
      GAMAW=CAREA*RDXG(IX)                                                     S0002380
      GCONE1=GAMAE+GAMAW                                                       S0002390
      GCONE2=GAMAE*TEM(IE)+GAMAW*TEM(IW)                                       S0002400
      GO TO 410                                                                S0002410
  401 GAMAE=CONE*AREAE(IYW)*RDXG(IXP1)                                         S0002420
      GCONE1=GAMAE                                                             S0002430
      GCONE2=GAMAE*TEM(IE)                                                     S0002440
      GO TO 410                                                                S0002450
  405 GAMAW=CONE*AREAE(IYW)*RDXG(IX)                                           S0002460
      GCONE1=GAMAW                                                             S0002470
      GCONE2=GAMAW*TEM(IW)                                                     S0002480
  410 CONTINUE                                                                 S0002490
      GRADI1=SIGMA*(TEM(IWAL)+TEM(I))*(TEM(IWAL)**2+TEM(I)**2)
     1 /(1.0/(AREAN(I)*EMIS10)+REMI/AREAN(IWALS))                              S0002500
      GRADI3=GRADI1                                                            S0002510
      GRADI4=GRADI1*TEM(I)                                                     S0002520
      SU(IYW)=RU11*TEM(I)-U11                                                  S0002530
      SL(IYW)=GCONE2+GRADI1*TEM(IWAL)+U11+U10                                  S0002540
      SP(IYW)=-GCONE1-GRADI1-RU11-RU10                                         S0002550
      SU(IYWP1)=RU10*TEM(I)-U10                                                S0002560
```

```
  415 CONTINUE                                                          S0002570
      CALL WALL(NYM1,STERM,STERM1,0,JH)                                 S0002580
      ST21=STERM                                                        S0002590
      H21=ST21*PHO(IWALS)*ABS(0.5*(U(IWALS)+U(IWALSW)))*CMIX            S0002600
      RU21=SXG(IX)/(1.0/(R21*H21)+ALNR21/COND)                          S0002610
      Q21=RU21*TEM(IWALS)                                               S0002620
      CALL WALL(NY,STERM,STERM1,0,JH)                                   S0002630
      ST20=STERM                                                        S0002640
      H20=ST20*RHOINF*ABS(UINF)*CMIX                                    S0002650
      RU20=SXG(IX)/(1.0/(R20*H20)+ALNR20/COND)                          S0002660
      Q20=RU20*TINF                                                     S0002670
      IF(IX.EQ.2) GO TO 416                                             S0002680
      CAREA=COND*WAREA                                                  S0002690
      GAMAE=CAREA*RDXG(IXP1)                                            S0002700
      GAMAW=CAREA*RDXG(IX)                                              S0002710
      GCOND1=GAMAE+GAMAW                                                S0002720
      GCOND2=GAMAE*TEM(IWALE)+GAMAW*TEM(IWALW)                          S0002730
      GO TO 420                                                         S0002740
  416 GAMAE=COND*WAREA*RDXG(IXP1)                                       S0002750
      GCOND1=GAMAE                                                      S0002760
      GCOND2=GAMAE*TEM(IE)                                              S0002770
  420 QRAD01=SIGMA*SXG(IX)*R20*EMIS20*(TINF+TEM(IWAL))                  S0002780
     1 *(TINF**2+TEM(IWAL)**2)                                          S0002790
      SU(NY)=GCOND2+QRAD14+QRAD01*TINF+Q21+Q20                          S0002800
      SP(NY)=-GCOND1-QRAD13-QRAD01-RU2I-RU20                            S0002810
      SU(NYM1)=RU2I*TEM(IWAL)-Q21                                       S0002820
C                                                                       S0002830
      IF(IX.NE.NXM1) RETURN                                             S0002840
      HEL3C=0.5*EL3/COND                                                S0002850
      DO 425 IY=2,NYM1                                                  S0002860
      I=IY+IX1NY                                                        S0002870
      IE=I+NY                                                           S0002880
      IV=IY+IX1NY1                                                      S0002890
      IVS=IV-1                                                          S0002900
      CALL WALL(NXM1,STERM,STERM1,IY,JH)                                S0002910
      STX1=STERM                                                        S0002920
      HX1=STX1*RHO(I)*ABS(0.5*(V(IV)+V(IVS)))*CMIX                      S0002930
      UX1=AREAE(IY)/(1.0/HX1+HEL3C)                                     S0002940
      QX1=UX1*(TEM(I)-TEM(IE))                                          S0002950
  425 SU(IY)=SU(IY)-QX1                                                 S0002960
      RETURN                                                            S0002970
  430 DO 435 IY=IYF,IYL                                                 S0002980
      I=IY+IX1NY                                                        S0002990
      IV=IY+IX1NY1                                                      S0003000
      IW=I-NY                                                           S0003010
      IVW=IV-NY-1                                                       S0003020
      IVSW=IVW-1                                                        S0003030
      IN=I+1                                                            S0003040
      IS=I-1                                                            S0003050
      CONDL=COND*EL3                                                    S0003060
      IF(IY.EQ.NY) GO TO 431                                            S0003070
      CALL WALL(NXM1,STERM,STERM1,IY,JH)                                S0003080
```

```
      STX1=STERM
      HX1=STX1*RHO(IY)*ABS(0.5*(V(IVN)+V(IVSW)))*CMIX                    S0003010
      UX1=AREAE(IY)/(1.0/HX1+HEL3C)                                      S0003020
      QX1=UX1*TEM(IX)                                                    S0003030
      GAMAN=COND1/ALOG(R(IY+1)/R(IY))                                    S0003040
      GO TO 432                                                          S0003050
  431 UX1=0.0                                                            S0003060
      QX1=0.0                                                            S0003070
      GAMAN=0.0                                                          S0003080
       CALL WALL(UX,STERM,STERM1,IY,JH)
       STX0=STERM
      HX0=STX0*RHOINF*ABS(VINF)*CMIX                                     S0003090
      UX0=AREA/(1.0/HX0+HEL3C)                                           S0003100
      GO TO 436                                                          S0003110
  432 CALL WALL(UX,STERM,STERM1,IY,JH)
      STX0=STERM
      HX0=STX0*RHOINF*ABS(VINF)*CMIX                                     S0003120
      UX0=AREAE(IY)/(1.0/HX0+HEL3C)                                      S0003130
  436 QX0=UX0*TINF                                                       S0003140
      IF(IY.EQ.2) GO TO 433                                              S0003150
      GAMAS=COND1/ALOG(R(IY)/R(IY-1))                                    S0003160
      GO TO 434                                                          S0003170
  433 GAMAS=0.0                                                          S0003180
  434 AN(IY)=GAMAN                                                       S0003190
      AS(IY)=GAMAS                                                       S0003200
      QRAD1=SIGMA*AREAE(IY)*(EMISX1+EMISX0)*(TINF+TEM(I))                S0003210
     1 *(TINF**2+TEM(I)**2)                                              S0003220
      AW(IY)=0.0                                                         S0003230
      SU(IY)=QRAD1*TINF+QX1+QX0                                          S0003240
  435 SP(IY)=-QRAD1-UX1-UX0                                              S0003250
      GAMAW=COND*WAREA*ROAG(IX)                                          S0003260
      SU(NY)=SU(NY)+GAMAW*TEM(IX1NY)                                     S0003270
      SP(NY)=SP(NY)-GAMAW                                                S0003280
      CALL WALL(NY,STERM,STERM1,0,JH)
      ST20=STERM
      H20=ST20*RHOINF*ABS(U1NF)*CMIX                                     S0003290
      R020=EL3/(1.0/(R20*H20)+ALNR20/COND)                               S0003300
      Q20=R020*TINF                                                      S0003310
      SU(NY)=SU(NY)+Q20                                                  S0003320
      SP(NY)=SP(NY)-R020                                                 S0003330
      RETURN                                                             S0003340
C-----------------------------------------------------------------------S0003350
CHAPTER  5  5  5  5  5  SOURCE TERMS FOR MIXTURE FRACTION  5  5  5  5  5S0003360
C-----------------------------------------------------------------------S0003370
   50 DO 52 IY=IYF,IYL                                                   S0003380
      SU(IY)=0.0                                                         S0003390
   52 SP(IY)=0.0                                                         S0003400
      RETURN                                                             S0003410
C-----------------------------------------------------------------------S0003420
CHAPTER  6  6  6  6  6  6  6  SOURCE TERMS FOR FUEL  6  6  6  6  6  6  6S0003430
C-----------------------------------------------------------------------S0003440
   60 T1=PREEXP*PRESS**2                                                 S0003450
```

```
      DO 62 IY=IYF,IYL                                                  S0003460
      I=IY+IX1NY                                                        S0003470
      FUBRNT=AMAX1(0.0,(FM(I)-FSTOIC)*RFSTM)                            S0003480
      FUEX=FUE(I)-FUBRNT                                                S0003490
      IF (FUEX.GT.0.0) GO TO 61                                         S0003500
      SP(IY)=-BIG                                                       S0003510
      GO TO 62                                                          S0003520
   61 FOX=AMAX1(TINY,STOICH*(FUE(I)-(FM(I)-FSTOIC)*RFSTM))              S0003530
      SP(IY)=-T1*EXP(-ARRCON/TEM(I))*VOL(I)*FOX*FUE(I)/FUEX             S0003540
   62 SU(IY)=-SP(IY)*FUBRNT                                             S0003550
      RETURN                                                            S0003560
C-----------------------------------------------------------------------S0003570
CHAPTER 7  7  7  7  7  7   SOURCE TERMS FOR PA  7  7  7  7  7  7  7  7  S0003580
C-----------------------------------------------------------------------S0003590
   90 ERROR=0.0                                                         S0003600
      IF (IX.EQ.2.AND.INC.EQ.-1) GO TO 93                               S0003610
      DO 92 IY=IYF,IYL                                                  S0003620
C     ERROR MASS SOURCES                                                S0003630
      ESMASS=-FLOWN(IY)+FLOWN(IY-1)-FLOWE(IY)+FLOWW(IY)                 S0003640
      SU(IY)=ESMASS                                                     S0003650
      SP(IY)=0.0                                                        S0003660
   92 ERROR=ERROR+ABS(ESMASS)                                           S0003670
      IF (IX.NE.NXM1.OR.INC.NE.1) GO TO 95                              S0003680
      SU(IYL)=0.0                                                       S0003690
      SP(IYL)=-BIG                                                      S0003700
      GO TO 95                                                          S0003710
C-----OUTLET BOUNDARY - UNIFORM PRESSURE ASSUMED.                       S0003720
   93 DO 94 IY=IYF,IYL                                                  S0003730
      SU(IY)=0.0                                                        S0003740
   94 SP(IY)=-BIG                                                       S0003750
   95 RSLINE(IX,JPP)=ERROR/RSREF(JPP)                                   S0003760
      ARSL(IX,JPP)=ABS(RSLINE(IX,JPP))                                  S0003770
      RETURN                                                            S0003780
      END                                                               S0003790
```

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of Mr. Guy Martin in proofreading the report and in preparing the diagrams and of Ms. Alana Anthony in typing the manuscript.